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# Long Term Optimum Performance/Corrosion Tests of Combustion Modifications for Utility Boilers. Host Site: Columbus and Southern Ohio Electric Co., Conesville No. 5

Exxon Research and Engineering Co.
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# LONG TERM OPTIMUM PERFORMANCE/CORROSION TESTS OF COMBUSTION MODIFICATIONS FOR UTILITY BOILERS

## Host Site: Columbus and Southern Ohio Electric Company
## Conesville No. 5

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The report gives results of part of a study of corrosion in large utility boilers firing high-sulfur coal, as possibly affected by combustion modifications (CMs) for decreased nitrogen oxide (NOx) emissions. During the first part of this study, each boiler was characterized to learn the short term effects of various CMs on boiler operation and emissions. Later, a Level 1 environmental assessment (EA) of boiler operation was performed, followed by tests to measure corrosion rates in the furnace. Also, two 30-day continuous emission monitoring (CEM) tests were performed. This report discusses work on Boiler No. 5 at Columbus and Southern Ohio Electric Co.'s Conesville (OH) generating station. During the short term characterization tests, full load NOx emissions (as equivalent $NO_2$) were reduced from 263 to 152 ng/J without adverse side effects. NOx emissions during the 30-day CEM tests were log-normally distributed with a mean of 180-224 ng/J and a geometric dispersion of 1.13-1.19. The Level 1 EA revealed no unusual environmental hazards resulting from low-NOx operation. For the nearly 2-year study, waterwall corrosion rates (measured ultrasonically) were similar to rates under normal operation at about 1-2 mils/yr.

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## ABSTRACT

Corrosion in utility boilers, as possibly affected by combustion modifications for decreased $NO_x$ emissions, was studied at large boilers burning high-sulfur coal. Under the first part of this program, each boiler was characterized to learn the short term effects of various combustion modifications on boiler operation, and emissions. Later, a Level 1 environmental assessment (EA) of boiler operation was performed, followed by tests to measure corrosion rates within the furnace. Also, two 30-day continuous emission monitoring (CEM) tests were performed. This report discusses the work performed on Boiler No. 5 at Columbus and Southern Ohio Electric Company's (C&SOE) Conesville generating station in Conesville, Ohio. During the short-term characterization tests, full load $NO_x$ emissions (as equivalent $NO_2$) were reduced from 263 ng/J (= 0.61 lb/MBtu = 446 ppm $NO_x$ at 3% $O_2$, dry) to 152 ng/J (= 0.35 lb/MBtu = 259 ppm $NO_x$ at 3% $O_2$, dry) without adverse side effects. $NO_x$ emissions during the 30-day monitoring tests were log-normally distributed with a mean of 180 to 224 ng/J and a geometric dispersion of 1.13 to 1.19. The Level 1 EA revealed no unusual environmental hazards resulting from low-$NO_x$ operation. For the nearly two year study, water wall corrosion rates (measured ultrasonically) were similar to rates under normal operation at about 1 to 2 mils per year.

This report was submitted in partial fulfillment of Contract No. 68-02-2696 by Exxon Research and Engineering Company under the sponsorship of the U.S. Environmental Protection Agency.

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## SUMMARY

For coal-fired utility boilers, $NO_x$ emission regulations can often be met by using combustion modification (CM) techniques such as decreased total excess air flow. However, this can lead to a chemically reducing atmosphere within the furnace and an increased corrosion potential. Under this program, methods of decreasing $NO_x$ emissions were studied (characterization testing) from both an environmental and a corrosion point of view. To this end, the program included four parts: Boiler characterization, Level 1 environmental assessment (EA), corrosion testing and thirty-day continuous emission monitoring (CEM). Several large utility boilers were studied during this long-term performance/corrosion study. This report deals with the Number 5 boiler at Columbus and Southern Ohio Electric Company's Conesville Generating Station.

### BOILER CHARACTERIZATION

Under the first part of this study, Exxon Research and Engineering Company (ER&E) identified and evaluated several combustion controls which could be used to modify the combustion process for decreased $NO_x$ emissions. Three of these combustion modifications were selected for detailed study, namely:

- o Decreased total excess air flow
- o Increased overfire air flow
- o Upward overfire air nozzle tilt.

By optimizing these controls, full load $NO_x$ emissions (as equivalent $NO_2$) were decreased from 263 ng/J (= 0.61 lb/MBtu = 446 ppm $NO_x$ at 3% $O_2$, dry) to 152 ng/J (= 0.35 lb/MBtu = 259 ppm $NO_x$ at 3% $O_2$, dry), without adverse short-term side effects. (The applicable NSPS allowable emission rate is 301 ng/J.)

In addition, by using the data from these boiler characterization tests, an improved operating procedure was adopted for medium and full load operation.

As expected, flue gas and fuel analysis for sulfur confirmed that the majority of fuel sulfur is converted to $SO_2$ and then delivered to the scrubber for subsequent clean-up.

Furnace gas sampled within the combustion zone (near the furnace waterwalls) revealed that the lowest CO concentrations were in the hopper zone, and that the region where corrosion was most likely (low $O_2$, high CO) was in the chemically reducing environment around the burner zone. Following the characterization work, corrosion in this and other regions was studied in greater detail using corrosion probes and sonic, non-destructive tube wall thickness measurement methods.

In the "as-found" condition, $NO_x$ emissions from the Conesville No. 5 boiler were well within the applicable New Source Performance Standard (NSPS) limit (301 ng/J). As a result of this program, the full load $NO_x$ emissions, as $NO_2$, were reduced 42% (decreased from 263 ng/J to 152 ng/J). This data was

## SUMMARY
## (CONTINUED)

used to set up and "fine tune" the boiler, resulting in improved operating procedures with no adverse short-term side effects. Long-term effects (such as corrosion) were studied in detail as the program continued.

### LEVEL 1 ENVIRONMENTAL ASSESSMENT (EA) TESTING

A Level 1 environmental assessment (EA) test was performed at Conesville No. 5 and involved the major inlet and effluent streams crossing the plant's process boundaries. The streams sampled included the inlet and outlet of the electrostatic precipitator, the precipitator hopper catch, the fuel feed, and the sluice water flushing the furnace hopper.

The Level 1 test was performed as a screening study to determine potential pollutants in the various streams and included three types of analysis. First, chemical analysis was used to determine the chemical composition of the various streams. Physical analysis on particles entrained in various streams provided information on shape, and size. Finally, biological analysis was used to gather information on the toxic, or mutagenic effects of the various streams on living matter.

As expected, most of the flue gases leaving the combustor and going to cleanup devices are fixed gases ($O_2$, $CO_2$, $N_2$, etc.). Other components of this stream include sulfur compounds, hydrocarbons, and entrained particulate matter.

The particulate matter (fly ash) represents more than 60% of the total ash leaving the system (the rest is slag or bottom ash and exits by another stream, i.e., by the sluice water stream to the settling pond). More than 98% of the fly ash, (mostly the larger particles) is removed by cleanup devices upstream of the stack.

The particulate matter and entraining flue gases contained low levels of organics (mostly alkyl esters) with concentrations of most metals near or below detectable levels. Organic matter on particulate favored the smaller particles. At the precipitator inlet, the particles were generally spherical, and were composed mostly of silicate material.

The fly ash particles sampled from the precipitator hopper were less spherical than the sample at the precipitator inlet, and ranged from 1 to 40$\mu$ m, and, like the ash entering the precipitator, contained mostly silicates.

While these tests were underway, supplemental tests were performed by Acurex Corporation. The Acurex data (Appendix I) shows that as the sluice water passes through the system, there is an increase in acidity, total suspended solids, chemical and biological oxygen demand, and total organic carbon. The effluent sluice water samples contained very low levels of metal anions.

## SUMMARY
## (CONTINUED)

The coal extract was separated into 7 fractions, but the spectra of each fraction were generally too complex to be analyzed by EPA Level 1 procedures. Instead, the major peaks are listed in the report, and show that the extract was highly aromatic, highly oxygenated material containing phenolic material, carboxylic acids, amides, and aliphatics. Most aromatic rings had two or more substituents. Mono-substituted aromatics were rare.

Biological tests (using living matter) were used to assess the environmental effect of process effluents on life forms, and indicated that the coal, electrostatic precipitator (ESP) ash, and sluice water from boilers tested under this program were not mutagenic. The Rat Alveolar Macrophage (RAM) Assays were also negative. The Chinese Hamster Ovary (CHO) Cell Assay yielded toxic responses with coal leachates and sluice water. Moderate to high toxicity was also recorded for some of the aquatic assays. Sluice water caused no toxicity to any of the aquatic species studied, but was stimulatory to the growth of algae.

### CORROSION TESTS

In order to more fully evaluate the longer term side effects of "low-$NO_x$" operation, corrosion testing began at the conclusion of the characterization period. Corrosion rate was measured by three methods:

- Corrosion probes
- Corrosion panels
- Wall thickness mapping

For the corrosion probes, as the exposure time increased, the rate of metal loss seemed to decrease (from more than 70 mils/yr to less than 20 mils/yr) and thus, the loss rate for the probes approached the loss rate for the furnace walls (which the probes were designed to simulate).* The corrosion panels had an average loss rate of 1.04 mils per year which compares well with the average wall loss rate of 1.39 mils per year. These rates are not unlike those for normal boiler operation.

No correlation was found between corrosion rate and location in the furnace. Furthermore, the T-22 material seemed to corrode at the same rate as the SA-210 material. No eccentric tube wear or loss of roundness was noticed, and the tubes close to the burners did not corrode measurably faster than those farther from the flame. On the average, the rate of corrosion within this boiler was such that it would require more than 30 years for the tubes to lose half their thickness. Therefore, corrosion rates, while operating in compliance with NSPS $NO_x$ regulations, appear to be acceptable.

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*Experience (EPA contract 68-02-1415) indicates that in the short term probe tests, corrosion occurs at an accelerated rate. The probe tests should therefore be used for qualitative comparisons only and should not be considered to represent actual wall corrosion rates. The panel and wall measurements are believed to more accurately reflect the true wall corrosion rates.

## SUMMARY
## (CONTINUED)

### THIRTY-DAY CONTINUOUS EMISSION MONITOR (CEM) TESTS

Twice during the program, flue gas emissions were monitored for thirty-day periods using continuous emissions monitors (CEM) to help researchers understand the abilities, problems and performance limitations that might be associated with CEMs in similar situations. The data also proved useful for evaluating boiler emissions over normal load cycles for longer periods than during the earlier (characterization) tests.

For the first 30-day CEM test, the normal probability curve of the 24-hour averages has a mean NO value of 227 ng/J with a standard deviation of 23. For the second CEM test, a log-normal curve seemed to be a better fit, and had a mean NO value of 180 ng/J (0.41 lb/MBtu) with a geometric dispersion of 1.12.

Although the boiler steam load varied widely (for example, from approximately 80 percent to 40 percent of maximum capacity during the first CEM test) the NO emission rate was fairly steady with the standard deviation being about 10 percent of the mean value. For the first test, the NO emissions data appear to be normally distributed with 99 percent of the data less than 295 ng/J (0.69 lb/MBtu). Similarly, for the second test, the NO emissions rate and excess oxygen levels were fairly steady with both showing standard deviations of about 9 percent of the mean value. The NO emissions rate was determined to be log-normally distributed for the second test with 99 percent of the values less than 230 ng/J (0.53 lb/MBtu). This is less than both the original (1971), and new (1979) NSPS limits (300 ng/J [0.7 lb/MBtu] and 260 ng/J [0.6 lb/MBtu], respectively).

The continuous monitor system (utilizing an extractive sampling system) provided accurate gaseous emissions data for the test duration. However, both calibration of the instruments on a daily basis, as well as maintenance of the sampling system are necessary.

# PART A

# PROGRAM INTRODUCTION AND GENERAL DESCRIPTION OF THE TEST UNIT

## I. INTRODUCTION

Under the sponsorship of the United States Environmental Protection Agency (EPA) (EPA Contract No. 68-02-1415), Exxon Research and Engineering Company (ER&E) studied the effects of boiler operating conditions on oxides of nitrogen ($NO_x$) emissions. These studies led to improved operating procedures for $NO_x$ control. The new procedures (known as combustion modifications (CM)) included decreased excess air flow, staged combustion, and other modifications. However, these modifications could increase the chemically reducing nature of the gases in certain regions of the furnace. The result could be an increased corrosion rate on the fireside of the boiler's waterwall tubes, especially in boilers fueled by high-sulfur coal.

In this program (EPA Contract No. 68-02-2696), furnace wall corrosion was studied at several coal-fired utility boilers, designed to use CM for decreased $NO_x$ emissions. The modifications included overfire air, and use of special low-$NO_x$ burners in order to meet the applicable new source performance standards (NSPS) for $NO_x$ emissions (301 ng/J, or 0.7 pounds/MBtu, as $NO_2$).

## II. PROGRAM STRATEGY

The test program contained several phases including:

- Boiler Characterization
- Corrosion Testing by
  - Probes
  - Panels
  - Wall measurements
- Level 1 environmental assessment
- 30 day continuous $NO_x$ monitoring

In the boiler characterization phase of the work, effects of various boiler combustion controls were assessed and their ability to control $NO_x$ emissions without causing short-term adverse side effects (such as increased slagging) were evaluated. This resulted in optimized operating procedures for $NO_x$ control and system flexibility.

During this time, flue gas emissions and fuel and ash composition were monitored. Also, furnace gas composition was monitored at various locations along the furnace wall in order to identify locally corrosive environments for further study.

Corrosion testing was initiated after the boiler characterization phase of this work. Three methods (corrosion probes, corrosion panels, and wall thickness mapping) were used to evaluate corrosion.

Corrosion probes were used to evaluate short term (30 to 1000 hours) corrosion effects. In this method, pieces of wall tube type materials (called corrosion coupons or test rings) were inserted into the furnace for various times and then weighed to determine the rate of metal loss. This qualitative, indirect method did not give a true reading of actual wall losses, but it was an economically attractive alternative to methods which require entrance into the furnace during an outage to measure the tubes directly as discussed below.

The corrosion panel method was probably the most reliable method used for measuring corrosion. In this method, sections of the boiler wall were removed, and replaced by new sections called corrosion panels on which the tube wall thickness had been carefully measured. About two years later, the furnace was reentered (during an outage) and the panels were re-measured. The wall thickness measurements were made ultrasonically, a nondestructive test in which sound waves are bounced off the inner wall of the tube and the thickness is determined from the echo time delay.

The third method used to measure corrosion was the wall thickness mapping method. This method involved ultrasonic thickness (UT) measurements of all walls throughout the furnace. The first set of such wall measurements occurred during the outage in which the corrosion panels were installed, and the second set was about two years later (coincident with the final panel measurements).

During these long term corrosion tests, an EPA Level 1 environmental assessment (EA) test was performed. It included physical, chemical, and biological (toxicity) analysis of the major streams entering or leaving the boiler. The Source Assessment Sampling System (SASS Train) was used to sample the flue gas stream while Method 17 was used to measure particulate removal efficiencies. Other streams sampled included sluice water, coal, and ESP hopper ash.

Twice, during the two year corrosion exposure period, $NO_x$ and other flue gases were monitored continuously for 30 days using a continuous emission monitoring (CEM) system. The 30-day CEM tests provided a better quantification of flue gas emissions over normal boiler load cycles and for a longer period than was possible during the characterization tests. These tests also gave the researchers an indication of how a CEM may be expected to perform (reliability, accuracy, maintenance needs, etc.) in other similar situations.

## III. BOILER DESCRIPTION

Conesville No. 5 is the fifth boiler constructed at Columbus and Southern Ohio Electric Company's (C&SOE) Conesville Generating Station in Conesville, Ohio. Designed by Combustion Engineering (CE) Inc., it uses combustion modifications (e.g., overfire air) to guarantee compliance with the applicable New Source Performance Standards (NSPS) for $NO_x$ emissions (0.7 pounds/MBtu or 301 ng/J $NO_x$ as $NO_2$), and is one of the first utility boilers to be governed by this NSPS regulation.

Burning nearly 200 tons per hour of high-sulfur coal (high corrosion potential), Conesville No. 5 uses Tangential Firing in a single-compartment, balanced-draft, water-wall boiler, to produce about 3,000,000 pounds of super-heated steam (1000°F, 2800 psi) per hour. This steam drives a turbine to produce more than 400 MW of electric power for C&SOE's residential and industrial customers in the Columbus, Ohio area.

Fuel (crushed coal) enters the plant by conveyor belts feeding five storage silos. Each silo has about six to eight hours of storage capacity (if the boiler is operating at full load). From the silo, the coal drops to a feed rate controller, and then to a mill where it is pulverized into a fine powder (one mill for each silo).

Primary air (about 20% or less of the total combustion air) enters the mill and blows the pulverized coal into the furnace. Each of the five pulverizers feeds four burners at a single elevation (one in each corner of the furnace). Any one or more of the five elevations of burners (four burners per elevation, 20 burners total) can be shut down by stopping the mill and its associated feeder.

As the fuel leaves the burner nozzle and enters the furnace, secondary and tertiary air sources (called fuel air and auxiliary air) mix with it, and once inside the furnace, its ignition temperature is quickly reached and combustion is sustained.

The burner and air nozzles are designed to produce a cyclonic vortex within the boiler by aiming each burner, tangent to an imaginary circle at the center of the boiler. Furthermore, the nozzles can be tilted up and down to direct the heat where it is needed within the furnace.

Air enters the boiler by any of four ways all located in the corners of the furnace. Primary air is used to blow the pulverized coal into the boiler. Secondary air (called fuel air) enters through ports surrounding each fuel nozzle. The tertiary air (called auxiliary air) enters through ports located between each adjacent pair of burners as well as below the bottom ones. Finally, overfire air (OFA) enters at two elevations above the top burners. The OFA nozzles can be tilted up or down independently of the burner tilts to control the separation between the overfire air and the flame.

For each corner of the boiler, all air (except for the primary air) is supplied by a single pressurized manifold (called the windbox). The distribution of the windbox air to the various ports feeding the furnace is controlled by a series of dampers.

Downstream of the furnace, the gaseous combustion products pass through a series of heat exchangers where energy is transferred to the steam being produced and/or to the incoming air. Next, the gases pass through a precipitator for dust removal, through a scrubber for $SO_2$ control, and finally up the stack.

The densest portion of the unburned coal (ash) falls into a water-filled hopper at the bottom of the furnace where it is quenched and periodically flushed to a settling pond. The lighter ash is carried by the combustion gases to the precipitator where these fly ash particles are captured electrostatically. This dry, powdery fly-ash catch is emptied from the precipitator hoppers periodically by a vacuum system.

Other smaller fractions of the fly ash are collected in any of several hoppers between the furnace and the precipitator.

## IV. NOMENCLATURE

The rear wall of the boiler is (by definition) the wall closest to the stack. Other walls (front, left, right) are named as seen by an observer standing in the turbine room, and facing the boiler with the stack on the far side.

The corners of the boiler are assigned numbers one through four starting in the front left, and running counter clockwise (plan view) (opposite to the cyclonic flow direction).

Generally, when number or letter designations are used to name sides or ducts, the "A" side or "1" side is on the west (left) of the unit.

Burner elevations are labeled A through E, with A on the bottom. Above the burners are OFA levels FF and GG (GG on Top).

For the purposes of this report, the tubes making up the furnace walls are numbered from left to right on each wall, as seen by an observer standing inside the boiler. (Note: this is opposite to CE's convention.)

# PART B

# CHARACTERIZATION TESTS

## I. PURPOSE OF CHARACTERIZATION TESTING

**The "Boiler Characterization" phase of this work was designed to assess the effects of the boiler's operating controls and then to optimize their set points for lowest $NO_x$ emissions without causing adverse side effects such as excessive CO emissions or increased slagging and corrosion. This "tuning" of the boiler for improved long term operation was conducted just prior to initiation of corrosion testing on each boiler in the program.**

## II. EXPERIMENTAL PROCEDURES FOR THE CHARACTERIZATION TESTS

### A. $NO_x$ Controls Investigated

**Boiler characterization at Conesville No. 5 involved the investigation and evaluation of four boiler combustion control parameters. The selection of these four parameters for study was based, in part, on boiler manufacturer's experience with $NO_x$ control, and the desire to gain additional knowledge that could help to "set-up" this new boiler which had only recently moved out of its initial "start-up" period.**

**The four boiler combustion controls selected for study were:**

- **Amount of Excess Air**
- **Overfire Air Flow**
- **Overfire Air Nozzle Tilt (Up or Down)**
- **Burner Nozzle Tilt (Up or Down)**

**The effects of other combustion controls, and boiler operating parameters on $NO_x$ emissions were also noted during the tests, but they were not studied in detail since the operator's ability to manipulate and control them was tightly constrained by the boiler design and load demand, and thus were not really suitable methods of $NO_x$ control. These included:**

- **Firing pattern**
  - **Mills out of service**
  - **Bias Firing**
  - **Staging (not reasonably possible on this boiler)**
- **Load**

## B. Other Boiler Operating Data

### 1. Control Room Readings

During each test, all important available information concerning the boiler's mode of operation was recorded. Most of these data were available on the display board in the control room through a data logging computer and as such are called "control room" (CR) or "board" readings in this report. The large volume of such data collected makes it impractical to present all of it in this report. Instead, as an example, the control room data sheets from tests 69-71 are presented in Appendix A.

### 2. Coal Analysis

Coal samples were gathered periodically for analysis. (This was in addition to the daily analysis done by C&SOE.) The purpose of the analysis was to determine what factors in the coal (heating value, sulfur, nitrogen) might be contributing to the performance of the boiler (e.g.: flue gas flow rate, $NO_x$ and $SO_2$ emissions). Coal analysis results are given in Appendix B.

## C. Effects Monitored

During the characterization period, ER&E measured the short term (from a few minutes to a few days) effects of modifications in the four combustion control parameters mentioned in the previous section. The goal was to minimize the boiler's $NO_x$ emissions through combustion modifications (CM) without creating problems in boiler operation or control. The effects measured included:

- Flue gas composition (at economizer outlet)
  - $O_2$
  - $NO_x$ (NO and $NO_2$)
  - CO
  - $CO_2$
  - $SO_x$ ($SO_2$ and $SO_3$)
- Stack plume opacity (measured by C&SOE's own in-stack transmissometer, and by an EPA certified observer)
- Furnace gas composition (searched for corrosive local environments)
  - $O_2$
  - CO
- Slag within the furnace (by observation through inspection doors)
- Boiler control flexibility

Figure B-II-1 is a simplified sketch of Conesville No. 5 and is referenced in the following discussion of sampling and testing.

1. Flue Gas

Figure B-II-2 shows the gas sampling and analysis system. Flue gas was sampled downstream of the boiler's economizer section and upstream of the air heater. Hence, the sample represented combustion products rather than leaks from downstream components. The sampling location is marked "A" on Figure B-II-1. At this location, the gas being sampled was about 500 to 800°F. Sampling tubes were assembled in four bundles of three and inserted horizontally through ports on the side of the single exhaust duct. Each bundle of three sampling tubes (called a "probe") consisted of a short, medium, and long tube of 3/8" stainless steel.

The twelve sampling points were located as close as possible to the centers of twelve equal and mutually exclusive co-planar areas of the duct's cross section. The gas was analyzed as a composite sample, three points (one probe) at a time. This method, though not in strict accord with EPA's Method 1, has been shown to yield a representative sample.*

For each probe, the three samples flowed through heated Teflon lines into a heated gas mixing and conditioning box. In the box, particulate matter was filtered from each sample, while still hot and free of condensed moisture. The three flow rates were then equalized and combined. As the sample exited the heated box, it flowed through a permeation tube dryer where water was selectively removed. Old style boxes (Figure B-II-2-B), incorporating flat disk filters were used through test 71. New style boxes (Figure B-II-2-C) incorporating cylindrical by-pass filters and air eductors were put in service after test 71. Both systems used permeation tube dryers to remove water.

Typically, the raw sample contained about 8% water vapor mixed with particulate matter. The heated, gas-conditioning boxes first removed the particulate matter, and then the water, thus preventing the formation of "mud" in the sampling lines. Removal of water allowed the sample to be subsequently cooled without fear of condensation which may have absorbed water soluble sample components such as $NO_x$, or in cold weather may have frozen and plugged the lines. With the water removed, the sample was

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*A. R. Crawford, M. W. Gregory, E. H. Manny, "Magnitude of $SO_2$, NO, $CO_2$, $O_2$, Stratification in Power Plant Ducts," Exxon Research and Engineering Company, EPA Report No. EPA - 600/2-75-053, September, 1975. Prepared under EPA Contract No. 68-02-1722.

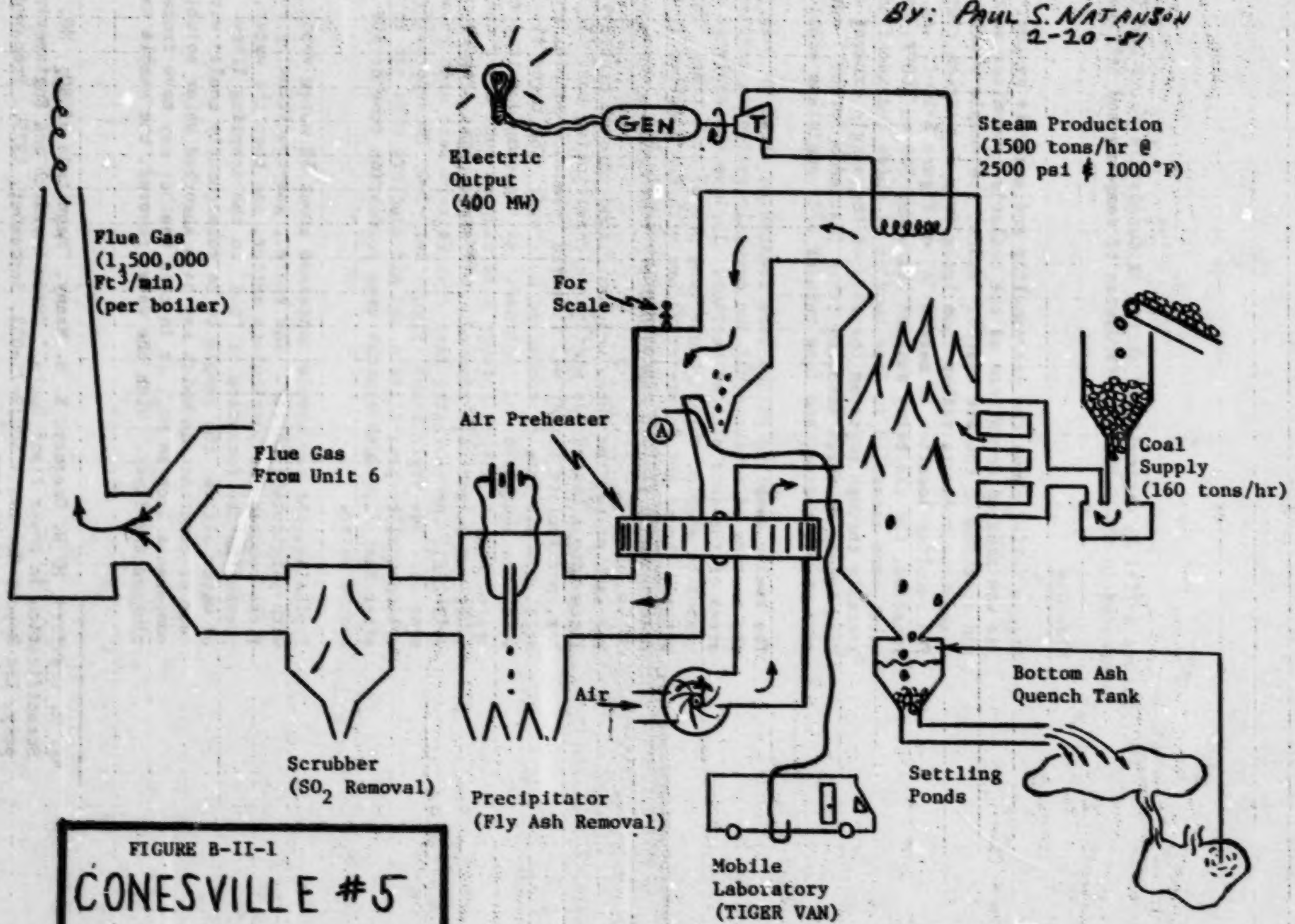
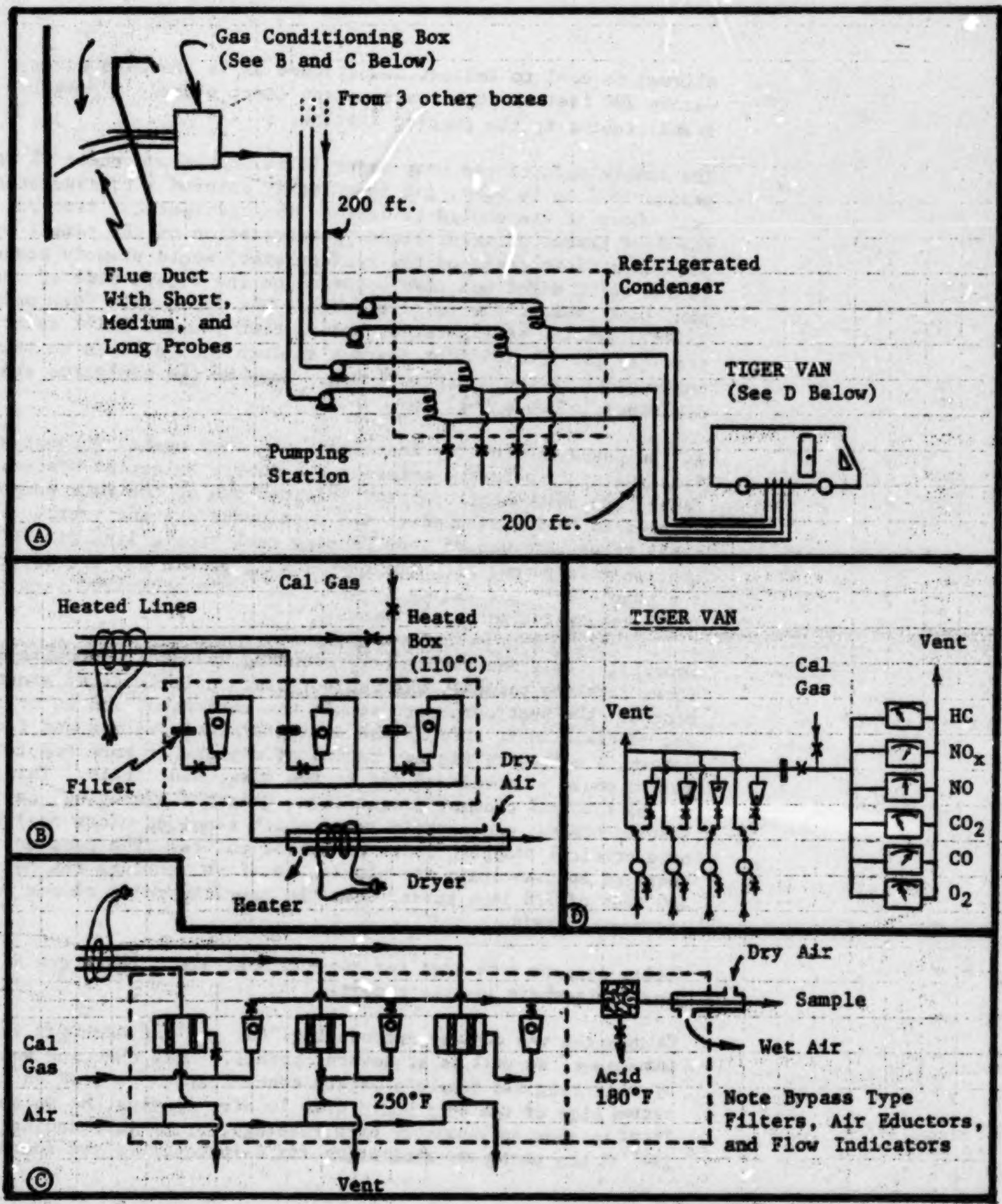

By: Paul S. Natanson
2-20-81

FIGURE B-II-1

CONESVILLE #5

SCHEMATIC OF PROCESS FLOW



BY: PAUL S. NATANSON 2-22-81

Figure B-II-2 Flue Gas Sampling and Analysis System

A - General Layout
B - Detail of Early Gas Conditioning Box
C - Detail of Newer Gas Conditioning Box
D - Detail of Mobile Analytical Van

allowed to cool to ambient temperature as it traveled under vacuum 200 feet through transluscent inert plastic ("Polyflo" brand) tubing to the pumping station.

The sample entered the pump under 15 in. Hg vacuum where it was pressurized to 10 psig, and immediately entered a refrigerated coil where it was cooled to 35°F.* The refrigerator removed the last traces of water since pressurization of the sample by the pumps (downstream of the refrigerator) would promote condensation which might not have occurred on the vacuum side of the pump (upstream of the refrigerator). The dry sample (dew point <35°F) left the refrigerated condensation chamber still under pressure for its 200 foot journey through teflon lines to the instruments in the analytical van. Some of the analyzers are described in Table B-II-1.

As the gases entered the instrument van they passed through a final water trap before entering the sample selection system. There, the instrument operator selected one of the four composite samples to be distributed to the continuous gas analyzers. The other three were vented thus keeping each sample line filled and continuously purged with its own flowing sample all the way to the sample selector valves in the van. This minimized response time when switching sample lines.

Generally, only one sample (representing an equal composite of three sampling points), was monitored at a time. After about two minutes, the next composite sample was monitored, and so forth. For special tests, through use of the system's valves and flowmeters, a composite (in any ratio) of any one or more sample points could be mixed and fed to the instrument train. This was useful for leak checks, diagnostics, weighted averaging, calibration checks, and certain tests which required close monitoring of a critical sampling point or set of points. The sample required approximately two minutes to travel through the nearly 400 feet of 3/8 inch tubing from the sampling point to the instrument train.

(Other systems were used for $SO_2$-$SO_3$ analysis. These are discussed elsewhere in this report.)

Calibration was done by introducing "cal gas" at each gas analysis instrument, as well as at several probes. Leak checking was done by monitoring the sample's oxygen concentration (a leak on the vacuum side of the pump would draw in air, causing the $O_2$ analyzer to show an unusually high reading), or by introducing "cal-gas" at the probe and monitoring its dilution. It was found

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*During some tests, mechanical problems prevented the use of the refrigerated condenser.

## TABLE B-II-1

### MOBILE ANALYTICAL LABORATORY: CONTINUOUS GAS MONITORS AND CALIBRATION STANDARDS

| Gas Monitored | Method | Manufacturer & Model | Measuring Ranges | Calibration Standard* |
|---|---|---|---|---|
| NO | non-dispersive infrared (NDIR) | Beckman | 0-400 ppm<br>0-2000 ppm | 3 |
| $NO_2$ | non-dispersive ultraviolet (NDUV) | Beckman | 0-100 ppm<br>0-400 ppm | 4 |
| $NO/NO_x$ | chemiluminescent | Thermo Electron 10 A | 0-25 ppm<br>0-10 ppm<br>0-25 ppm<br>0-100 ppm<br>0-250 ppm<br>0-1000 ppm<br>0-2500 ppm<br>0-10000 ppm | 3 & 4 |
| $O_2$ | polarographic | Beckman | 0-5%<br>0-25% | 2 & 5<br>6 |
| $CO_2$ | non-dispersive infrared (NDIR) | Beckman | 0-20% | 2 |
| CO | non-dispersive infrared (NDIR) | Beckman | 0-200 ppm<br>0-1000 ppm<br>0-25000 ppm | 2<br>1 |
| $SO_2$ | non-dispersive infrared (NDIR) | Beckman | 0-600 ppm<br>0-3000 ppm | 7 |
| HC** | flame ionization detector (FID) | Beckman | 0-10 ppm<br>0-100 ppm<br>0-1000 ppm | 2 |

* See Table B-II-2 for composition of calibration gas mixtures. In all cases nitrogen (mixture No. 8) was used for the "zero" check.

**HC = Hydrocarbons (Since unheated sample lines were used, only volatile hydrocarbons could be sampled and delivered to the analyzer. Low boiling point hydrocarbons were lost in the sample lines.)

## TABLE B-II-2

## COMPOSITION OF STANDARD GAS MIXTURES USED FOR CALIBRATION OF GAS ANALYZERS (THIS TABLE FOR USE WITH TABLE B-II-1)

**COMPOSITION**

| MIXTURE NUMBER | COMPONENTS | CONCENTRATIONS* |
|---|---|---|
| 1 | CO | 15,000 PPM |
| 2 | CO<br>$CO_2$<br>$CH_4$<br>$H_2$<br>$O_2$<br>$H_2O$ | 150 PPM<br>13%<br>25 PPM<br>1%<br>4-5%<br>Dry |
| 3 | NO | 450 PPM |
| 4 | NO<br>$NO_2$ | 450 PPM<br>45 PPM |
| 5 | $O_2$ | 4% |
| 6 | Air | 100% |
| 7 | $SO_2$ | 500 PPM |
| 8 | $N_2$ | 100% |

In addition to the above, National Bureau of Standards (NBS) gases were kept and used as reference checks when accepting new calibration gases from suppliers. Each cylinder of calibration gas could be checked against its NBS counterpart.

*Nitrogen makes up the balance of all mixes.

that as long as the oxygen analyzer indicated no critical leaks, it did not matter, except for CO, whether calibration was done at the probe or at the gas analyzer. In the case of CO, it was discovered that the reading drifted upward very rapidly unless the instrument was cleaned frequently. Hence, some of the early CO readings may be falsely high. The composition and use of the calibration gases is summarized on Table B-II-2.

When evaluating operating parameters, such as combustion modifications, during boiler characterization tests, the testing team would first wait for the boiler to reach steady state. Then at two minutes intervals, the flows in each of the four sample lines would be fed, in turn, to the gaseous analyzers and the results would be recorded on a form suitable for computer processing. The cycle was repeated until each of the four sample streams had been analyzed three to five times.

The next step was typically to have the boiler operator adjust the boiler's combustion parameters (such as amount of excess air) for another test, wait approximately 1/2 hour for steady state, and analyze the flue gas as before. Each such test required about an hour.

At the conclusion of a testing visit, the data would be computer processed and reported in terms of a standard dilution - usually 3% oxygen.

Many tests involved adjustment of excess oxygen flow and subsequent observation of its effect on $NO_x$ emissions. During setup for these tests, air flow was slowly decreased until CO emissions began to rise. To help monitor the boiler from its control room, a remote indicator was installed in the control room which echoed the $O_2$, CO, and $NO_x$ readings displayed in the analytical van. During test setup, the instrument operator in the van switched the sample selector to monitor a location in the flue gas exhaust duct where the $O_2$ and CO concentrations were most critically low or high, respectively. Hence, as the boiler operator decreased the air flow rate, he was able to see almost immediately, on the remote indicator, how this was affecting CO and $NO_x$ emissions. Observers in both the control room and the analytical van kept in constant radio contact during boiler set up. Visible stack emissions were frequently monitored by an EPA-certified plume observer.

Each test began after a short observation period to be sure that the boiler was operating in steady state. Once in steady state, the control room observer recorded all critical boiler operating parameters so that emissions could be correlated with operating mode.

Until recently, emission monitoring equipment had not been a standard part of most boilers' instrumentation, and for lack of it, some boilers may have been operated at higher air feed rates than necessary for complete combustion. Even now, most boilers are not equipped with a CO monitor to aid in decreasing air flow. The excess air goes up the stack as wasted heat, lost efficiency, and $NO_x$.* The equipment used in these tests helped to control these effects.

### 2. $SO_2$ and $SO_3$ Analysis

A modified version of EPA Methods 6 and 8 was used to analyze flue gas for $SO_2$ and $SO_3$. A sketch of the system is shown in Figure B-II-3.

Flue gas was withdrawn under vacuum from the flue duct and bubbled through a series of impinger bottles containing solutions designed to absorb $SO_2$ and $SO_3$, respectively.

The first impinger contained isopropyl alcohol (IPA) to absorb $SO_3$. It was followed by peroxide ($H_2O_2$) solutions for absorbing $SO_2$. The amounts absorbed were determined by titration. For $SO_3$ determination, barium perchlorate ($BaCl_4$) was the titrant, and thorin was the colorometric indicator. For $SO_2$, the titrant and indicator solutions were sodium hydroxide (NaOH) and methyl-orange, respectively.

### 3. Plume Opacity

Plume opacity was measured by an EPA-certified smoke reader.** In addition to the observer, the data from the in-stack transmissometer were also recorded on the control-room board-data sheets.

### 4. Gaseous Samples at Furnace Wall

Another type of gaseous sampling (called furnace gas-tap testing) involved extracting gases directly from various places along the walls of the combustion zone so that local potentially corrosive environments could be identified and selected for further study.

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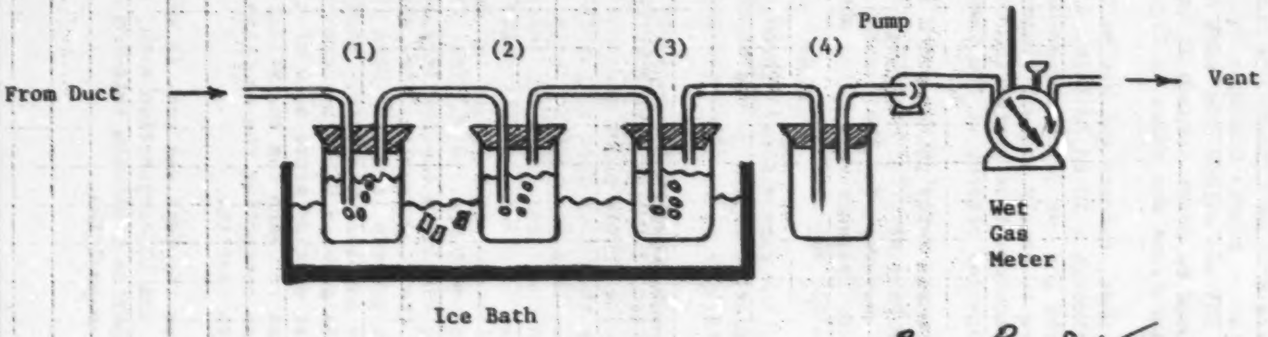
*See also: When it Pays to Monitor CO "Power" magazine, (McGraw Hill Publications Co., New York), Vol. 125, No. 8, Aug, 1981, pg. 37.

**In order to be certified, the observer must "read," consecutively, 25 samples of black smoke, and 25 of white smoke from (randomly) 0 to 100% opacity. No reading may be in error by more than 15 percentage points, and the average error in both the black and white categories must each be less than 7-1/2 percentage points as compared to a calibrated in-stack transmissometer.

Figure B-II-3: $SO_2$-$SO_3$ SAMPLING SYSTEM.



By: Paul S. Natanson

(1) 100 ml of 80% Isopropopyl alcohol (IPA) in water absorbs $SO_3$

(2) 100 ml of 3% $H_2O_2$ in water absorbs $SO_2$ as well as any $SO_3$ not absorbed by the first impinger.

(3) 100 ml of 3% $H_2O_2$ in water. This is a back up to impinger #2. If impinger #2 should become saturated, #3 will absorb any $SO_x$ that gets through #2.

(4) This empty trap helps keep the pump dry.

In preparation for the furnace gas tap study, approximately forty 1/4 inch holes were drilled through the furnace wall (in the membrane between adjacent tubes) during a boiler shutdown. A 1/4 inch pipe (0.24" ID) was welded over each hole so that a sample of furnace gas could be drawn through it from outside the boiler. Furnace gas tap locations are shown in Figure B-II-4.

During a gas tap test, furnace gas was pulled, under vacuum, from the furnace and through a 10 to 20 foot, 3/8" stainless steel (SS) coil where the gas was quickly quenched from its more than 2000°F temperature to nearly ambient temperature. This quenched the combustion reactions thus preserving for analysis, the incompletely reacted species present at the sampling point.

Of course, this caused water condensation in the sampling lines which in turn may have absorbed some $NO_x$ and produced a falsely low $NO_x$ reading. However, for the purpose of these tests, in which corrosive environments were being screened, little emphasis was placed on the $NO_x$ reading.

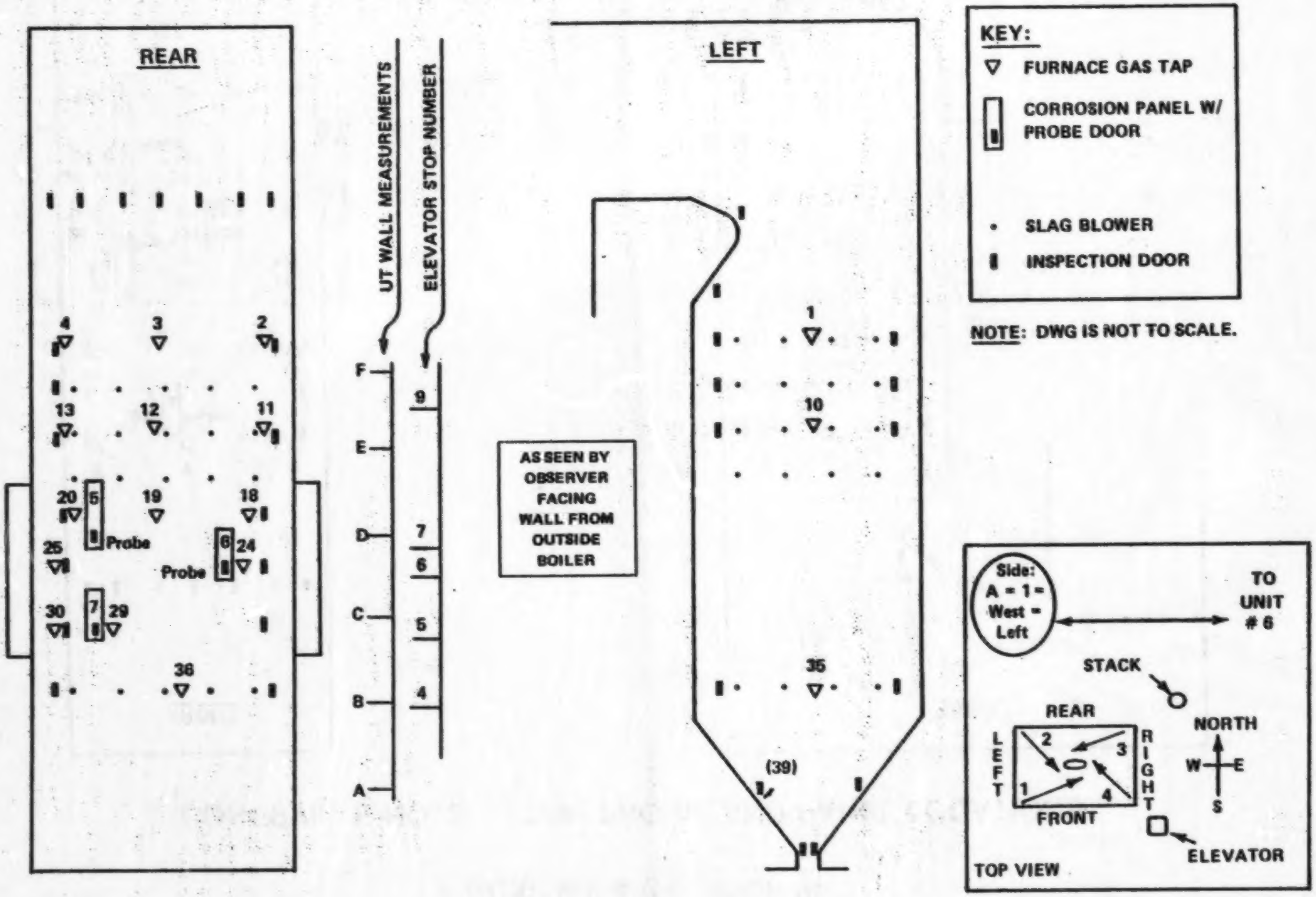
From the SS coil, the sample flowed through about 200 feet of 3/8" "Polyflo" brand plastic tubing to one of the three inlet ports on a gas conditioning box. (The other two ports were valved off.)

The remainder of the sampling and analysis train was the same as described in Section II.C.1 of Part B of this report except that the line between the sample point and conditioning box was 200 feet long, rather than four feet as was the case when the flue duct was sampled. This was because during the multi-point sampling procedure in the furnace gas tap tests (40 sampling points), it was impractical to place a conditioning box close to each sampling port. Instead, only one or two boxes were used, and these remained in one place. A 200 foot "Polyflo" line was used to bring the sample to the box (one line for each box). The other end of the long sampling line was hand-carried and connected to each gas tap in turn. When two boxes were used, only one could be sampled at a time. Meanwhile, the other sampling line would be purging with the next waiting sample. This saved a great deal of time since each of the 40 samples, required 3-4 minutes to reach the analytical van. Because of the length of the line connecting the sampling port with the box, it was impractical to heat it.

When a furnace gas tap test was run, it was usually done shortly before or after, and in conjunction with, a flue duct test. This allowed comparisons between emission data, operating mode, and furnace gas composition.

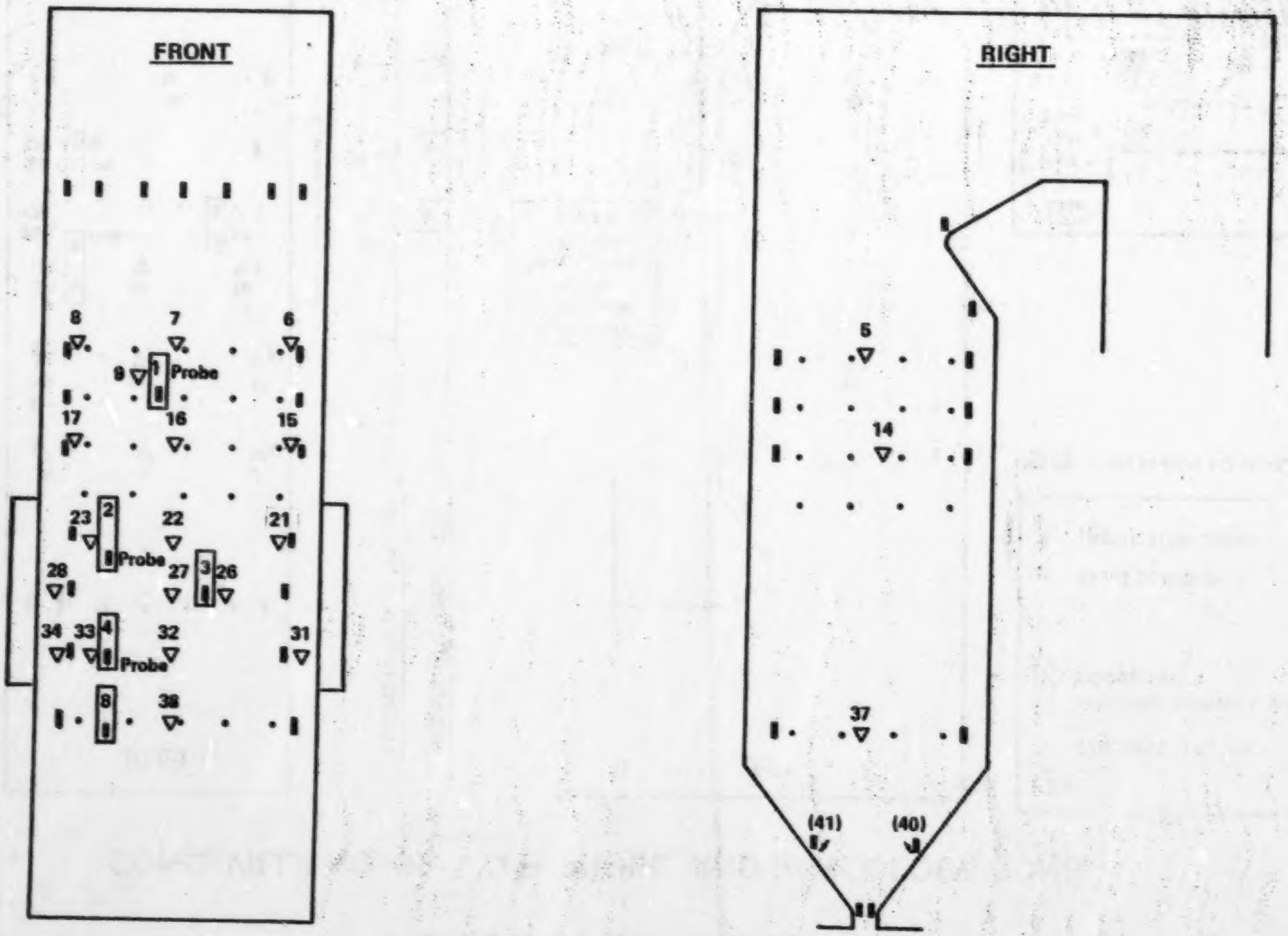
## FIGURE B-II-4 (PG. 1 OF 2)

## CONESVILLE NO. 5: TAP, PROBE, AND PANEL LOCATIONS



## FIGURE B-II-4 (PG. 2 OF 2)

## CONESVILLE NO. 5: TAP, PROBE, AND PANEL LOCATIONS



## III. RESULTS OF CHARACTERIZATION TESTS

### A. Summary of Test Conditions and Independent, Controlled Test Parameters

Before presenting the results, it would be helpful to know the conditions under which each test was performed, as well as a few other parameters for cross referencing the test information.

By far, the most common type of testing was the analysis of flue gas composition at the economizer outlet duct just upstream of the air heater. Table B-III-1 lists the duct tests in order by test number and date. It also lists other tests and available information pertaining to the same time period as each duct test.

In Table B-III-2, tests done under similar operating conditions are grouped together for easy comparison. The reader should note that firing pattern (e.g.: mills in service, staging, etc.) although recorded, was not a parameter used to group the tests. This helps to explain why dissimilar emission rates were sometimes observed for tests having (according to Table B-III-2) similar operating conditions.

### B. Flue Gas Data (Continuous Monitors)

Flue gas test results are summarized in Table B-III-3, as well as in the apendixed report from Combustion Engineering Inc. (Appendix G). The detailed individual test data, too voluminous to present here, is exemplified in Appendix C. For $NO_x$ analysis, the "chemiluminescent $NO_x$" data are most accurate since these data suffer less from interferences and calibration drift than the IR data. The chemiluminescent data are shown on Table B-III-3 in the first column following the $O_2$ column.

In order to evaluate each of the four $NO_x$ control parameters investigated, it was necessary to choose the parameter of interest, and hold the others constant while the one of interest was varied from test to test.

#### 1. $NO_x$ and CO vs $O_2$

The extent of any chemical reaction can be decreased by decreasing the supply of one or more reactants. Hence, one would expect that decreased excess air flow (i.e: decreased oxygen concentration in the flue gas) would cause a corresponding decrease in $NO_x$ emissions. And, a plot of flue gas $NO_x$ vs $O_2$ should show a trend toward lower $NO_x$ at lower $O_2$.

The families of curves in Figures B-III-1 through B-III-3 show $NO_x$ vs $O_2$ for various sets of constants as indicated on each figure. Clearly, they show (as expected) that $NO_x$ emissions generally decrease as $O_2$ (excess air) is decreased.

## TABLE 5-III-1

### SUMMARY OF TEST CONDITIONS (IN ORDER BY TEST NUMBER AND DATE)

| Test | Test | Load | OFA Dampers (+% Open) | | Tilts (DEG UP) | | Air Flow | Mills | Comments |
|---|---|---|---|---|---|---|---|---|---|
| # | Date | (MW) | FF | RR | OFA | Burner | Rate* | Off | |
| 1 | 1/12/79 | | | | | | | | |
| 2 | 1/12/79 | 480 | 6 | 6 | 0 | 0 | Normal | | |
| 3 | 1/12/79 | 480 | 6 | 6 | 0 | 0 | Normal | | |
| 4 | 1/15/79 | | | | | | | All on | Practice test |
| 5 | 1/16/79 | 480 | 6 | 6 | 0 | 0 | Normal | Normal | Practice test |
| 6 | 1/16/79 | 483 | 6 | 6 | 0 | 0 | Low/Med | | Practice test |
| 7 | 1/17/79 | 465 | 6 | 30 | 0 | 0 | Medium | | |
| 8 | 1/17/79 | 466 | 6 | 30 | 0 | 0 | Low | | |
| 9 | 1/19/79 | 248 | 3 | 3 | 0 | 0 | Normal | E | |
| 10 | 1/22/79 | 481 | 3 | 3 | 0 | 0 | Medium | | |
| 11 | 1/22/79 | 487 | 30 | 30 | 0 | 0 | Normal | | |
| 12 | 1/23/79 | 487 | 30 | 30 | 0 | -5 | Low | All on Normal | |
| 13 | 1/23/79 | 480 | 100 | 100 | 0 | -5 | Low | | |
| 14 | 1/23/79 | 480 | 100 | 100 | 0 | -5 | Normal | | |
| 15 | 1/23/79 | 480 | 0 | 0 | 0 | -5 | Normal | | |
| 16 | 1/24/79 | 481 | 30 | 30 | +10 | 0 | Normal | | Includes SO$_3$ test |
| 17 | 1/24/79 | 382 | 30 | 30 | +10 | 0 | Normal | E | |
| 18 | 1/24/79 | 370 | 30 | 30 | +10 | 0 | Low | E | |
| 19 | 1/25/79 | 480 | 30 | 30 | +10 | 0 | Low | | |
| 20 | 1/25/79 | 480 | 0 | 30 | +10 | 0 | Low | | |
| 21 | 1/25/79 | 480 | 0 | 75 | +10 | 0 | Low | | |
| 22 | 1/25/79 | 484 | 75 | 75 | +10 | 0 | Low | | |
| 23 | 1/25/79 | 483 | 100 | 100 | +10 | 0 | Low | All on Normal | |
| 24 | 1/25/79 | 482 | 100 | 0 | +10 | 0 | Low | | |
| 25 | 1/25/79 | 480 | 75 | 75 | 0 | 0 | Low | | |
| 26 | 1/25/79 | 486 | 75 | 75 | 0 | 0 | Low | | |
| 27 | 1/30/79 | 323 | 3 | 3 | 0 | 0 | Normal | C | |
| 28 | 1/30/79 | 321 | 3 | 3 | 0 | 0 | Low | C | |
| 29 | 1/30/79 | 323 | 30 | 30 | 0 | 0 | Normal | C | |
| 30 | 1/30/79 | 327 | 30 | 30 | 0 | 0 | Low | C | |
| 31 | 1/31/79 | 323 | 100 | 100 | 0 | 0 | Normal | C | |
| 32 | 1/31/79 | 327 | 100 | 100 | 0 | 0 | Low | C | |
| 33 | 2/ 1/79 | 341 | 75 | 75 | 0 | 0 | Low | C | |
| 34 | 2/ 1/79 | 342 | 75 | 75 | +10 | 0 | Low | C | |
| 35 | 2/ 2/79 | [illegible] | 75 | 75 | -10 | 0 | Low | C | Sample Lines Plugged |
| 36 | 2/ 6/79 | 233 | 3 | 3 | 0 | -3 | Normal | C&E | |
| 37 | 2/ 6/79 | 230 | 30 | 30 | +10 | +10 | Low | C&E | |
| 38 | 2/ 6/79 | 234 | 75 | 75 | +10 | +10 | Low | C&E | |
| 39 | 2/ 6/79 | 233 | 100 | 100 | +10 | +10 | Low | C&E | |
| 40 | 2/ 6/79 | 232 | 3 | 3 | +10 | +10 | Low | C&E | |
| 41 | 2/ 7/79 | 305 | 3 | 3 | +10 | + 2 | Low | C | |
| 42 | 2/ 7/79 | 307 | 30 | 30 | +10 | + 2 | Low | C | |
| 43 | 2/ 7/79 | 309 | 100 | 100 | +10 | + 2 | Low | C | |
| 44 | 2/12/79 | 333 | 100 | 100 | 0 | 0 | Low | C | |
| 45 | 2/12/79 | 358 | 100 | 100 | 0 | 0 | Low | C | |
| 46 | 2/12/79 | 333 | 100 | 100 | -10 | 0 | Normal | C | |
| 47 | 2/16/79 | 147 | 0 | 0 | | -3 | Normal | A,B,AC | |
| 48<br>49 | These test numbers were not assigned | | | | | | | | |
| 50 | 3/17/80 | 316 | 3 | 3 | -10 | 0 | Normal | E | As found |
| 51 | 3/17/80 | 327 | 3 | 3 | -10 | 0 | Low | E | |
| 52 | 3/18/80 | 483 | 3 | 3 | -10 | + 7 | Normal | | Full load, as found conditions |
| 53 | 3/18/80 | 480 | 30 | 30 | -10 | + 7 | Normal | | |
| 54 | 3/18/80 | 480 | 30 | 30 | -10 | + 3 | Low | | |
| 55 | 3/18/80 | 480 | 100 | 100 | -10 | 0 | Normal | | |
| 56 | 3/18/80 | 480 | 100 | 100 | -10 | 0 | Low | | |
| 57 | 3/19/80 | 480 | 30 | 30 | -10 | + 7 | Normal | "E" Feeder As Running Slow | |
| 58 | 3/19/80 | 481 | 75 | 75 | -10 | + 3 | Normal | | |
| 59 | 3/19/80 | 486 | 75 | 75 | -10 | 0 | Low | | |
| 60 | 3/19/80 | 480 | 3 | 3 | -10 | 0 | Low | | |
| 61 | 3/21/80 | 480 | 75 | 75 | -10 | - 3 | Normal | | |
| 62 | 3/21/80 | 480 | 75 | 75 | -10 | - 3 | Med | | |
| 63 | 3/21/80 | 475 | 3 | 3 | -10 | - 2 | Normal | | |
| 64 | 3/24/80 | 410 | 3 | 3 | -10 | - 6 | Normal | | Includes SO$_3$, Coal, and Furnace Gas tests. E mill was shut down during this test. |
| 65 | 3/25/80 | 407 | 75 | 75 | -10 | - 1 | Low | E | Includes SO$_3$, Coal, & Furnace Gas Tests. |
| 66 | 3/26/80 | 315 | 75 | 75 | -10 | - 3 | Normal | | |
| 67 | 3/27/80 | 320 | 75 | 75 | -10 | 0 | Low | B off, E low | |
| 68 | 3/27/80 | 320 | 75 | 75 | -10 | 0 | Med | | |
| 69 | 4/ 4/80 | 327 | 75 | 75 | -10 | 0 | Normal | | |
| 70 | 4/ 4/80 | 320 | 75 | 75 | -10 | 0 | Low | C off, E Low | |
| 71 | 4/ 4/80 | 323 | 75 | 75 | -10 | 0 | Med | | Includes coal and 30 hr corrosion probe tests. |
| 72 | 9/18/80 | 405 | 63 | 70 | -11 | -11 | Normal | A | Includes Level 1 test performed jointly with Acurex Corp. |

*Air flow rates:
Normal - As usual plant practice.
Medium - Somewhat less than normal (lowest flow rate "easily" obtained).
Low - Lowest "safe" rate for safe CO emissions.

## TABLE B-III-2

## TESTS GROUPED BY TEST CONDITIONS

| Burner Tilt (Deg Up) | OFA* Tilt (Deg Up) | OFA Closed | | OFA 25% Open | | OFA 50% Open | | OFA 75% Open | | OFA Full Open | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Normal Air | Low Air | Normal Air | Low Air | Normal Air | Low Air | Normal Air | Low Air | Normal Air | Low Air |
| **FULL LOAD (≥400 MW)** | | | | | | | | | | | |
| +10 | +20 | | | | | | | | | | |
| | +10 | | | | | | | | | | |
| | 0 to -10 | 31 37 | | | | | | | | | |
| 0 | +10 | | | | | 16 | 19 20* | | 21* 22 | | 23 24*25* |
| | 0 | 2 3<br>10 13 | 6 | | | 7* 11 | 8* 12 | | 26 | 14 | 13 |
| | -10 | 63 64 | 60 | | | 33 | 34 | 38 61 | 37 63<br>62* | 35 | 36 |
| -10 | 0 | | | | | | | | | | |
| | -10 | | | | | | | 71 | | | |
| | -20 | | | | | | | | | | |
| **MEDIUM LOAD (200-400 MW)** | | | | | | | | | | | |
| +10 | +20 | | | | | | | | | | |
| | +10 | | | | | | | | | | |
| | 0 | | | | | | | | | | |
| 0 | +10 | | 41 | | | 17 | 18 42 | 44 68 71* | 22* | | 43 46 |
| | 0 | 27 | 28 | | | 29 | 30 | 69 | 67 70 | 21 | 72 65 |
| | -10 | 50 | 51 | | | | | | | | 45 |
| -10 | 0 | | | | | | | | | | |
| | -10 | | | | | | | | | | |
| | -20 | | | | | | | | | | |
| **LOW LOAD (200-300 MW)** | | | | | | | | | | | |
| +10 | +20 | | | | | | | | | | |
| | +10 | | [illegible] | | | | 57 | | 59 | | 58 |
| | 0 | 56 | | | | | | | | | |
| 0 | +10 | | | | | | | | | | |
| | 0 | 7 | | | | | | | | | |
| | -10 | | | | | | | | | | |
| 0 | 0 | | | | | | | | | | |
| | -10 | | | | | | | | | | |
| | -20 | | | | | | | | | | |
| **VERY LOW LOAD (≤ 200 MW)** | | | | | | | | | | | |
| +10 | +20 | | | | | | | | | | |
| | +10 | | | | | | | | | | |
| | 0 | | | | | | | | | | |
| 0 | +10 | | | | | | | | | | |
| | 0 | | | | | | | | | | |
| | -10 | 47 | | | | | | | | | |
| -10 | 0 | | | | | | | | | | |
| | -10 | | | | | | | | | | |
| | -20 | | | | | | | | | | |

*NOTES:

Generally, OFA tilts were tested at: (OFA tilt=burner tilt -10°), (OFA tilt=burner tilt), and (OFA tilt=burner tilt +10°).

Tests 62, 68 & 71 were done at medium air flow. (Air Flow rates are explained in the note on Table B-III-1.)

Tests 7, 8, 20, 21, 25: top OFA damper open as indicated, bottom closed.

Test 24 bottom OFA damper open amount indicated, top closed.

Test 33 is not a good test. (Line plugged.)

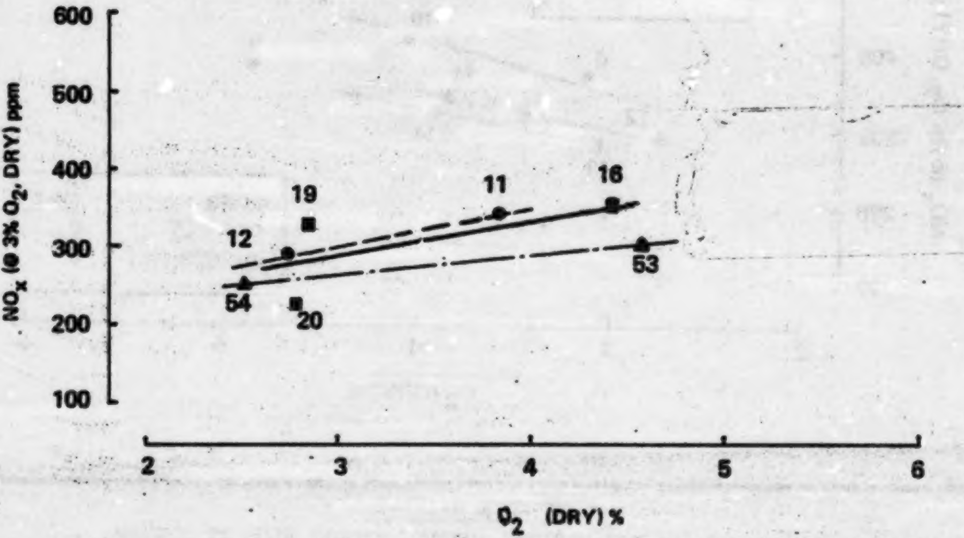
## TABLE B-III-3

## SUMMARY OF FLUE GAS COMPOSITION: ALL TESTS
(at 3% $O_2$, Dry Basis)

| TESTS NO. | $O_2$ (PCT) (MEAS) | $NO_x$ (CHEMI) (PPM) | NO (CHEMI) (PPM) | NO (NDIR) (PPM) | CO (PPM) | $CO_2$ (PCT) |
|---|---|---|---|---|---|---|
| 3 | 4.47 | 316. | 315. | 408. | 122. | 14.96 |
| 4 | 4.61 | 353. | 348. | - | 138. | 15.03 |
| 5 | 4.85 | 379. | 377. | 452. | 27. | 15.00 |
| 6 | 3.17 | 370. | 370. | - | 31. | 14.77 |
| 7 | 4.47 | 371. | 367. | - | 167. | 14.73 |
| 8 | 2.84 | 272. | 274. | - | 820. | 14.57 |
| 9 | 4.07 | 421. | 415. | 473. | 18. | 14.88 |
| 10 | 3.98 | 378. | 373. | 407. | 26. | 16.41 |
| 11 | 3.85 | 343. | 344. | 372. | 53. | 14.96 |
| 12 | 2.75 | 295. | 296. | 319. | 234. | 14.66 |
| 13 | 3.07 | 281. | 281. | 297. | 61. | 14.41 |
| 14 | 3.93 | 330. | 330. | 348. | 22. | 14.21 |
| 15 | 4.52 | 467. | 466. | 483. | 10. | 13.87 |
| 16 | 4.42 | 354. | 353. | 392. | 44. | 14.38 |
| 17 | 4.40 | 288. | 288. | 317. | 36. | 14.97 |
| 18 | 2.79 | 224. | 221. | 266. | 70. | 14.87 |
| 19 | 2.97 | 278. | 274. | 338. | 95. | 15.01 |
| 20 | 2.94 | 334. | 327. | 406. | 58. | 14.77 |
| 21 | 2.82 | 320. | 317. | 396. | 128. | 14.71 |
| 22 | 3.08 | 263. | 258. | 308. | 57. | 14.68 |
| 23 | 3.31 | 286. | 260. | 306. | 26. | 15.29 |
| 24 | 2.80 | 316. | 312. | 356. | 237. | 15.32 |
| 25 | 3.09 | 330. | 327. | 387. | 41. | 15.40 |
| 26 | 3.61 | 259. | 256. | 299. | 49. | 14.96 |
| 27 | 5.47 | 407. | 401. | 393. | 37. | 14.49 |
| 28 | 1.82 | 289. | 286. | 305. | 241. | 14.74 |
| 29 | 3.53 | 343. | 339. | 366. | 38. | 14.00 |
| 30 | 2.88 | 242. | 240. | 270. | 75. | 14.47 |
| 31 | 6.04 | 269. | 264. | 283. | 28. | 14.72 |
| 32 | 3.36 | 226. | 224. | 248. | 29. | 14.81 |
| 33 | 4.26 | 201. | 197. | 291. | 123. | 14.92 |
| 34 | 4.27 | 184. | 182. | 220. | 67. | 14.36 |
| 35 | 4.35 | 192. | 190. | 173. | 39. | 15.27 |
| 36 | 5.95 | 339. | 336. | 382. | 45. | 14.22 |
| 37 | 5.62 | 268. | 265. | 295. | 24. | 14.29 |
| 38 | 5.52 | 234. | 230. | 264. | 25. | 14.00 |
| 39 | 6.01 | 212. | 210. | 242. | 11. | 13.93 |
| 40 | 4.59 | 342. | 338. | 375. | 9. | 14.02 |
| 41 | 4.57 | 310. | 299. | 348. | 30. | 14.91 |
| 42 | 4.50 | 222. | 216. | 261. | 32. | 14.87 |
| 43 | 3.77 | 173. | 173. | 212. | 13. | 14.30 |
| 44 | 3.81 | 198. | 198. | 223. | 24. | 14.61 |
| 45 | 3.77 | 226. | 218. | 246. | 23. | 14.44 |
| 46 | 3.46 | 243. | 243. | 262. | 22. | 14.21 |
| 47 | 9.72 | 420. | 417. | 439. | 26. | 13.62 |
| 50 | 4.93 | 350. | 344. | 268. | 37. | 15.10 |
| 51 | 2.18 | 271. | 267. | 266. | 43. | 15.30 |
| 52 | 4.47 | 365. | 366. | 380. | 48. | 15.43 |
| 53 | 4.38 | 318. | 314. | 324. | 47. | 15.63 |
| 54 | 2.33 | 236. | 253. | 256. | 145. | 15.88 |
| 55 | 4.52 | 310. | 305. | 313. | 48. | 15.35 |
| 56 | 1.82 | 245. | 244. | 253. | 282. | 15.28 |
| 57 | 4.57 | 369. | 362. | 383. | 62. | 15.07 |
| 58 | 4.54 | 319. | 324. | 326. | 62. | 14.81 |
| 59 | 2.29 | 280. | 256. | 264. | 65. | 15.39 |
| 60 | 2.43 | 323. | 321. | 332. | 64. | 15.29 |
| 61 | 4.46 | 305. | 312. | 308. | 102. | 15.32 |
| 62 | 3.83 | 283. | 284. | 290. | 90. | 15.32 |
| 63 | 4.62 | 364. | 358. | 366. | 91. | 15.27 |
| 64 | 4.82 | 308. | 315. | 357. | 220. | 15.02 |
| 65 | 3.68 | 229. | 229. | 107. | 218. | 15.26 |
| 66 | 4.84 | 283. | 286. | 247. | 182. | 14.97 |
| 67 | 3.29 | 242. | 248. | 262. | 229. | 14.77 |
| 68 | 4.07 | 257. | 261. | 282. | 173. | 14.61 |
| 69 | 6.12 | 288. | 285. | 300. | 391. | 15.25 |
| 70 | 2.87 | 431. | 458. | 219. | 453. | 15.86 |
| 71 | 5.52 | 338. | 338. | 268. | 371. | 15.63 |
| 72 | 5.73 | 337. | 332. | - | 24. | 15.18 |

## FIGURE B-III-1

## $NO_x$ VS. $O_2$ FOR VARIOUS OFA TILTS AT FULL LOAD. 50% OFA, AND ZERO BURNER TILT



**KEY**

| TEST NUMBERS | SYMBOLS USED ON ABOVE GRAPH | TEST CONDITIONS | | | |
|---|---|---|---|---|---|
| | | LOAD | OFA % OPEN | OFA TILT | BURNER TILT |
| 16,19,20 | ■ ———————— ■ | FULL | 50 | +10 | 0 |
| 11, 12 | ● — — — — — — ● | FULL | 50 | 0 | 0 |
| 53, 54 | ▲ —·—·—·—·— ▲ | FULL | 50 | −10 | 0 |

FIGURE B-III-2

NO$_x$ VS. O$_2$ FOR VARIOUS AMMOUNTS OF OFA AT FULL LOAD, ZERO OFA TILT, AND ZERO BURNER TILT

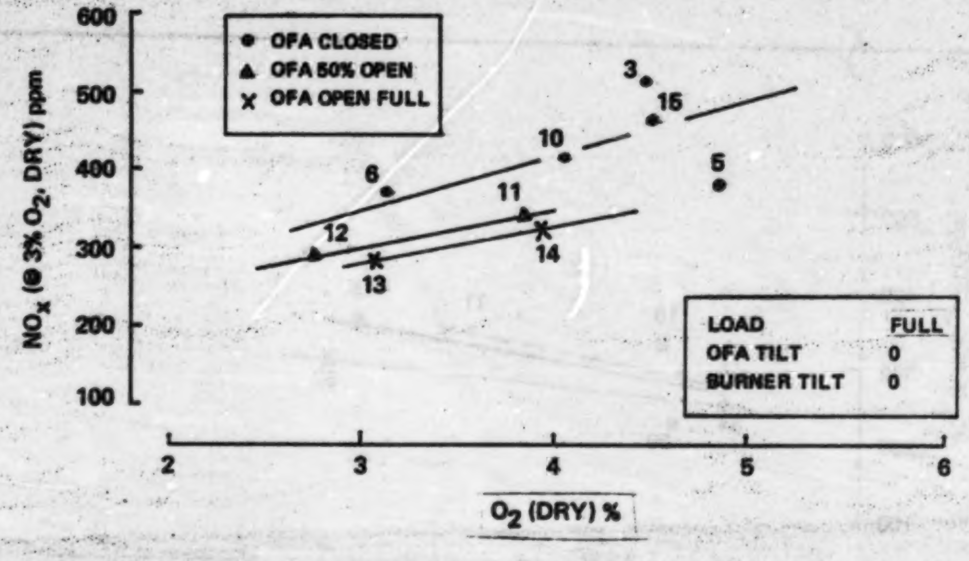
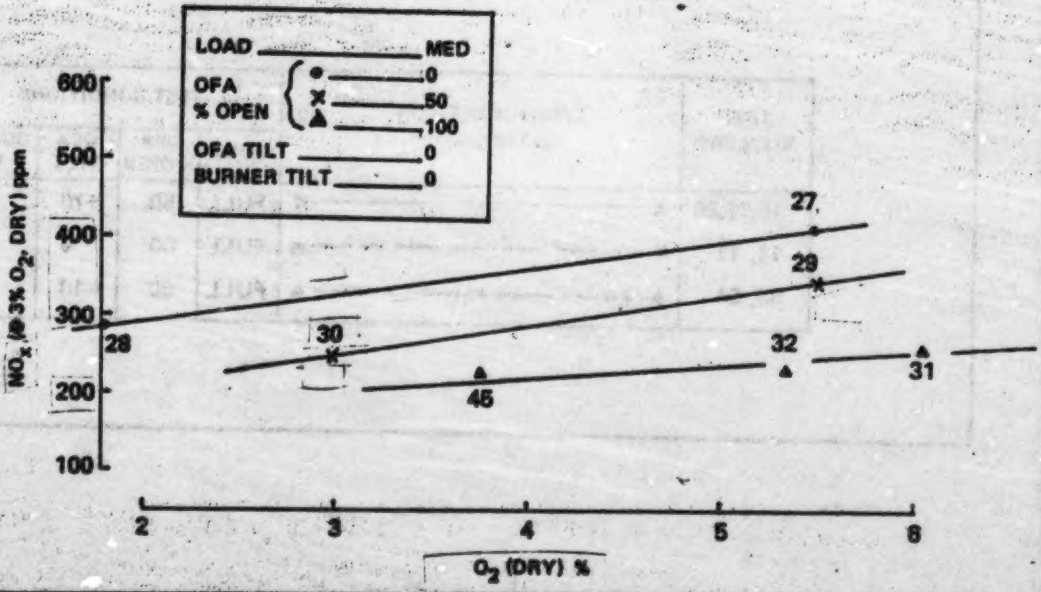


FIGURE B-III-3

NO$_x$ VS. O$_2$ FOR VARIOUS AMOUNTS OF OFA FLOW AT MEDIUM LOAD, ZERO OFA TILT, AND ZERO BURNER TILT



This and other trends shown in the figures are summarized below:

- $NO_x$ decreases as excess air is decreased (Figures B-III-1 through B-III-3).
- $NO_x$ decreases as overfire air (OFA) flow is increased. (See Figure B-III-2, or B-III-3.)
- $NO_x$ decreases as load decreases (compare the family of full load curves in Figure B-III-2 with the medium load curves in Figure B-III-3).
- $NO_x$ is more responsive to changes in air flow at higher loads than at lower loads. (The family of full load curves shown in Figure B-III-2 is steeper than the family of medium load curves shown in Figure B-III-3.)

From an operating point of view there is a safe limit beyond which the oxygen flow should not be further reduced because combustion will become unstable and inefficient, especially at low loads. During the testing period, $O_2$ was decreased only to the point where CO emissions began to increase. This occurred well in advance of problems such as loss of combustion efficiency or excess slagging. Hence, the CO monitor installed for these tests proved to be a useful tool for decreasing excess air flow to optimum levels.

Figure B-III-4 shows, hypothetically, how $NO_x$ and CO are affected by excess air. Note that as air flow is decreased, $NO_x$ emissions also decrease. However, during these and other tests, observers noticed that as air flow is decreased in preparation for each "low air" test, CO emissions remain almost unchanged until a certain threshold is reached were some of the burners may begin to "flicker," causing temporarily spikes in the flue gas CO concentration. Further decrease in excess air causes CO levels to climb steadily and rapidly.

Optimum low air levels were usually defined as somewhere between the onset of the flickering spikes, and the point where CO concentration crossed over 200 ppm. "Retuning" of the flickering burners could eliminate the spikes and allow the boiler to be operated at even lower excess air levels if a CO monitor were in use.

## 2. $NO_x$ vs Load

$NO_x$ emissions, whether reported on a ppm or pounds/hour basis, generally decreased as load was decreased. This is because as load is reduced, the ratio of heat input rate to heat transfer area decreases, resulting in a cooler flame and lower $NO_x$ production. However, load is not generally considered as a method

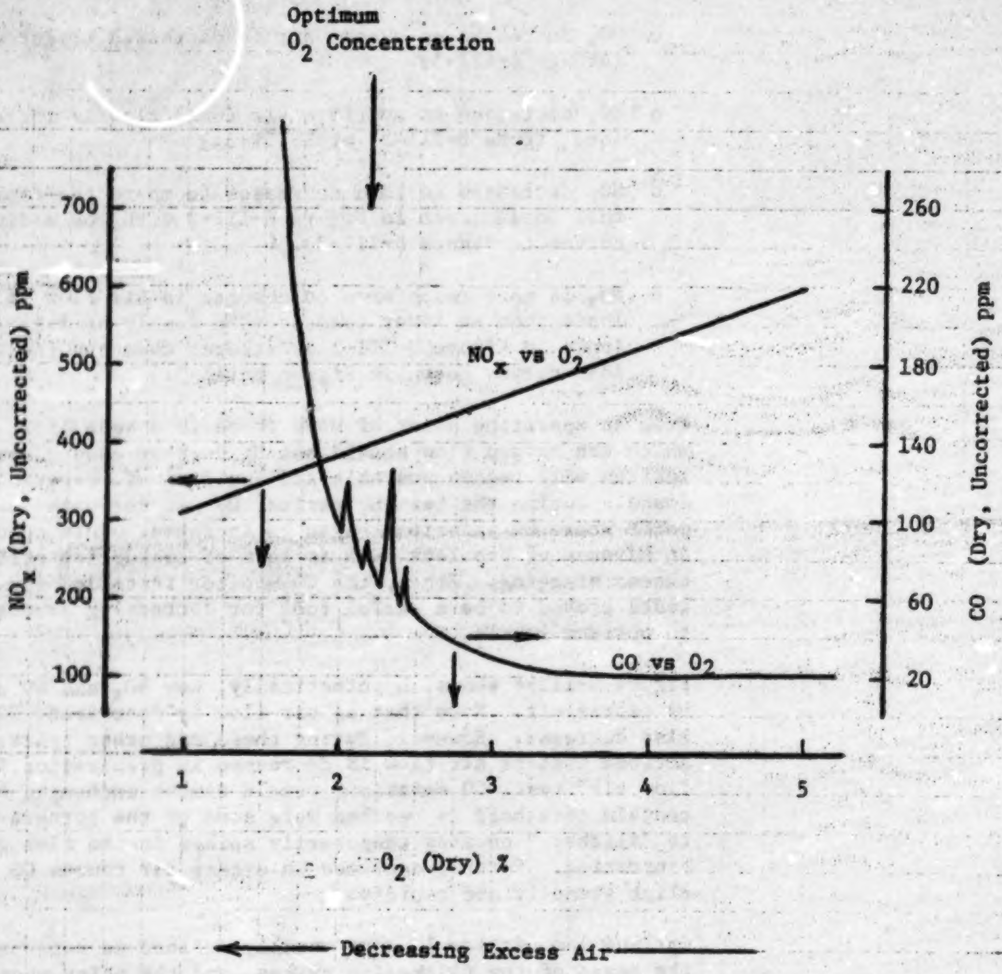


Figure B-III-4. CO Emissions During Reduction of Excess Air Flow for $NO_x$ Control for $NO_x$ control since economics and customer demand for electric power do not allow boiler operators to change load at will. In rare cases, boilers may be derated as a last resort for $NO_x$ control.

The families of curves in Figures B-III-5 and B-III-6 show some of the available data for $NO_x$ vs. load at various combinations of constant conditions.* For the loads tested, $NO_x$ emissions (per pound of fuel, for example) were relatively insensitive to load changes.

### 3. $NO_x$ vs. Overfire Air (OFA) Flow

Opening the OFA ports on this boiler redistributes (but does not change) the total air flow, causing more air to enter the furnace above the burner zone. Conesville No. 5 has two elevations (FF and GG) of OFA ports which can be opened independently. However, during the characterization tests, both were usually operated together and opened by the same amount for most tests. Only in tests 7, 8, 20, 21, 24 & 25 were FF and GG open differently from each other. FF is located a few feet above the burners, and GG is a few feet above FF. Analysis of the six tests with unequal OFA damper settings showed no trends.

The OFA dampers were never completely closed during any test. It was necessary to always have at least a small amount of air flowing through to cool them, and keep them clean. For the purpose of this report, 5% open is treated as closed.

The series of Figures B-III-7 through B-III-14 show how $NO_x$ emissions are affected by redistribution of the total air (for damper settings FF = GG). The figures show that by opening the OFA ports and thus redistributing the total air towards the top of the furnace, $NO_x$ emissions will decrease. Most of the possible $NO_x$ improvement occurs by the time that the dampers are 50% open.

### 4. $NO_x$ vs. Overfire Air (OFA) Nozzle Tilt

One might expect $NO_x$ emissions to decrease as the distance between the overfire air and the fire are increased. However, for this boiler, $NO_x$ emissions seemed to increase (but only slightly) as the overfire air nozzles were tilted upwards from horizontal. (Up is positive tilt. Horizontal = $0^\circ$ tilt.) This happened in about two thirds of the situations studied. The families of curves in Figures B-III-15 through B-III-18 are exemplary of the $NO_x$ vs. OFA tilt relationship. The family

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*In Figure B-III-5, a single line was used to represent data taken at two different OFA tilts. This was done because in most cases the effect of OFA tilt on $NO_x$ was small (as explained in the next few pages).

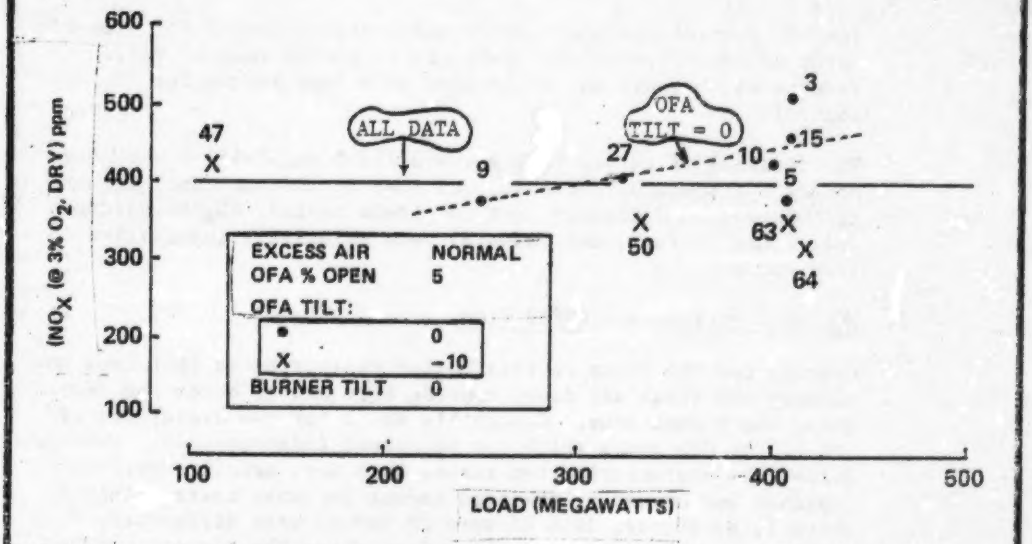

FIGURE B-III-5. $NO_x$ VS. LOAD AT NORMAL EXCESS AIR, OFA CLOSED, (OFA TILT EITHER 0° OR -10°) AND ZERO BURNER TILT.

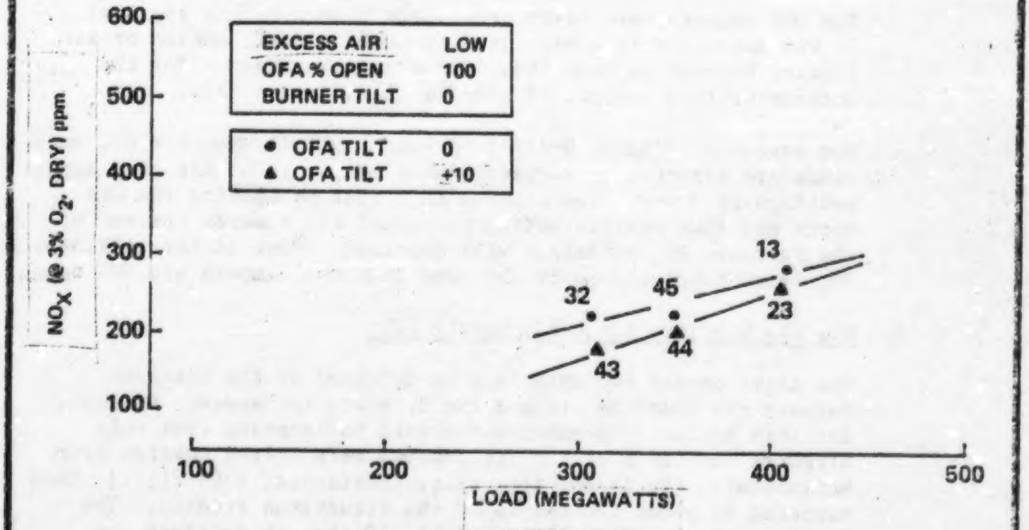

FIGURE B-III-6. $NO_x$ VS. LOAD FOR DIFFERENT OFA TILTS AT LOW EXCESS AIR, OFA 100% OPEN, AND ZERO BURNER TILT.

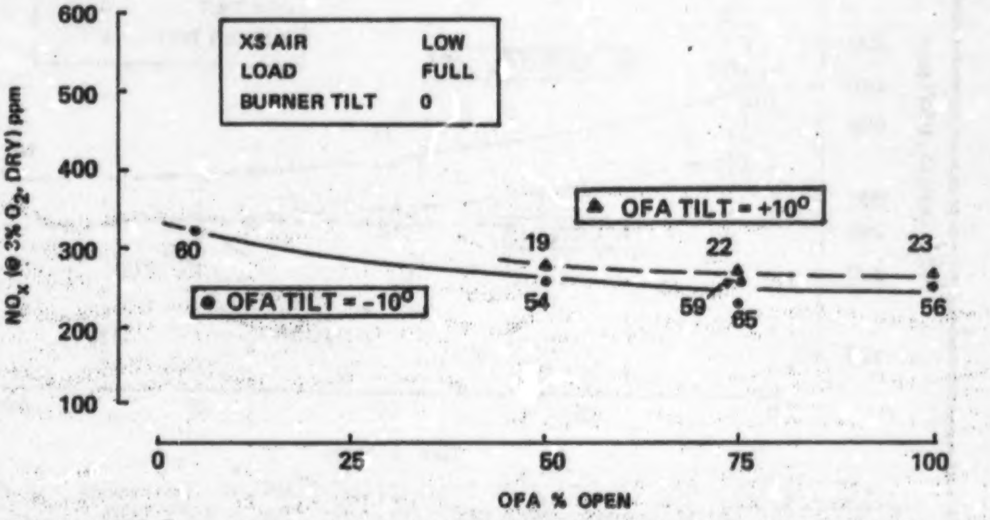

FIGURE B-III-7. NO$_x$ VS. OFA FLOW FOR DIFFERENT OFA TILTS AT LOW EXCESS AIR, FULL LOAD, AND NO BURNER TILT.

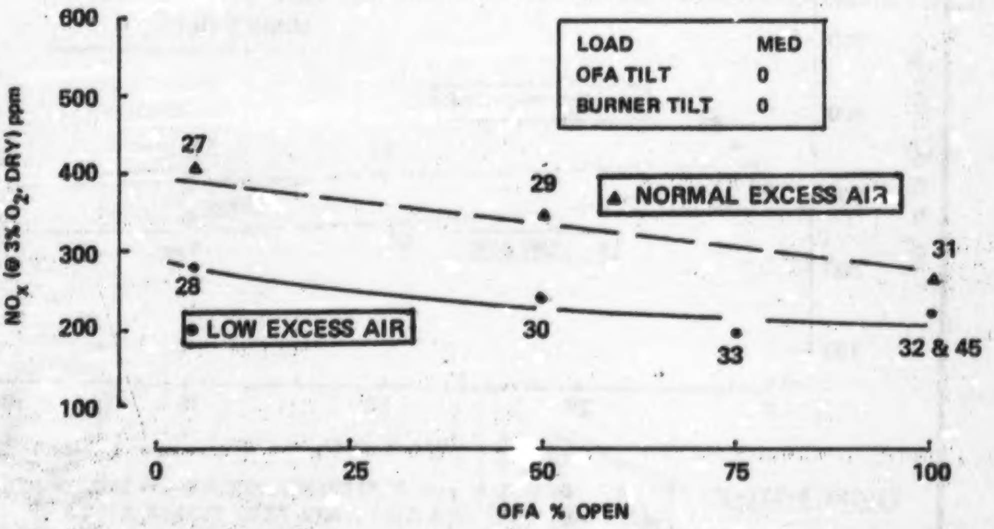

FIGURE B-III-8. NO$_x$ VS. OFA FLOW FOR DIFFERENT AMOUNTS OF EXCESS AIR AT MEDIUM LOAD, ZERO OFA TILT, AND ZERO BURNER TILT.

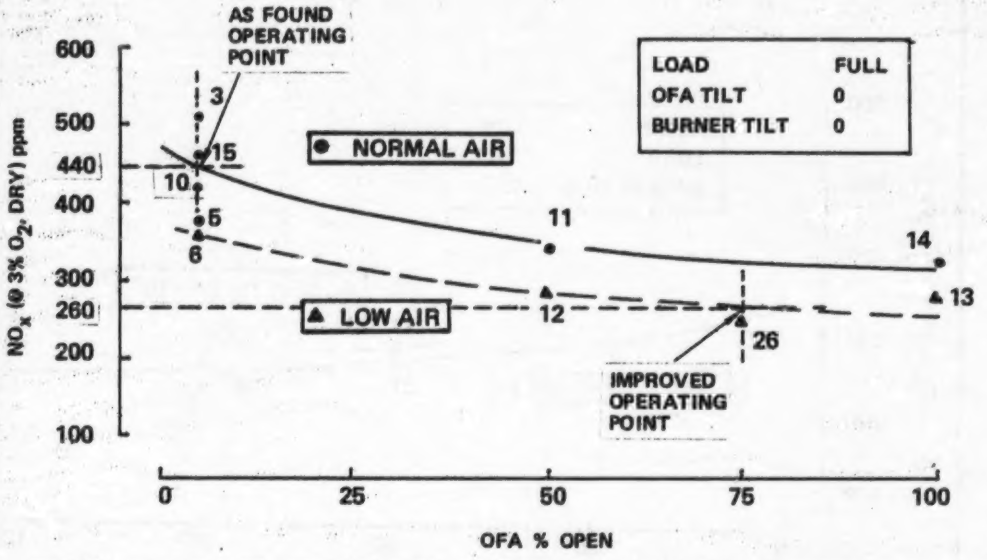

FIGURE B-III-9. NO$_x$ VS. OFA FLOW FOR DIFFERENT AMOUNTS OF EXCESS AIR AT FULL LOAD, ZERO OFA TILT, AND ZERO BURNER TILT.

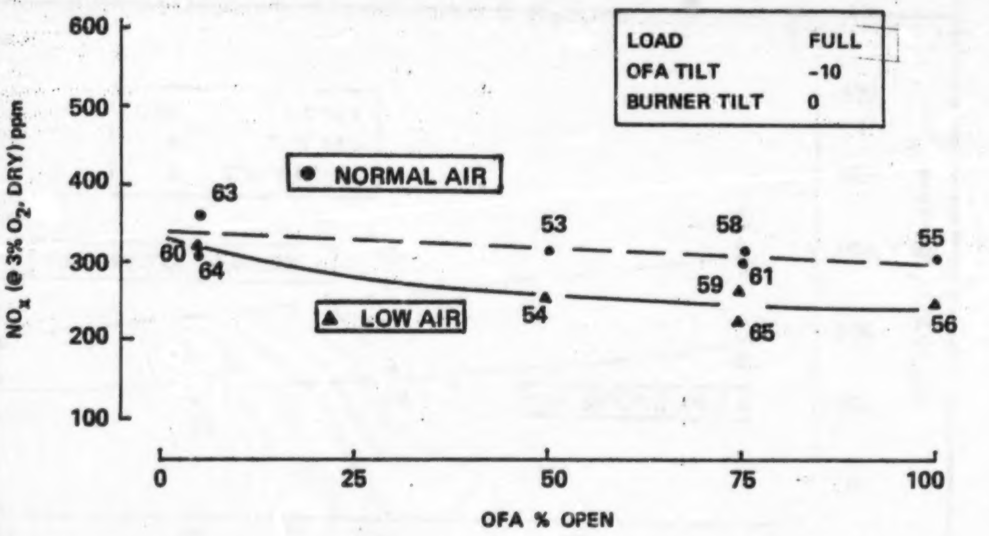

FIGURE B-III-10. NO$_x$ VS. OFA FLOW FOR DIFFERENT AMOUNTS OF EXCESS AIR AT FULL LOAD, -10° OFA TILT, AND ZERO BURNER TILT.

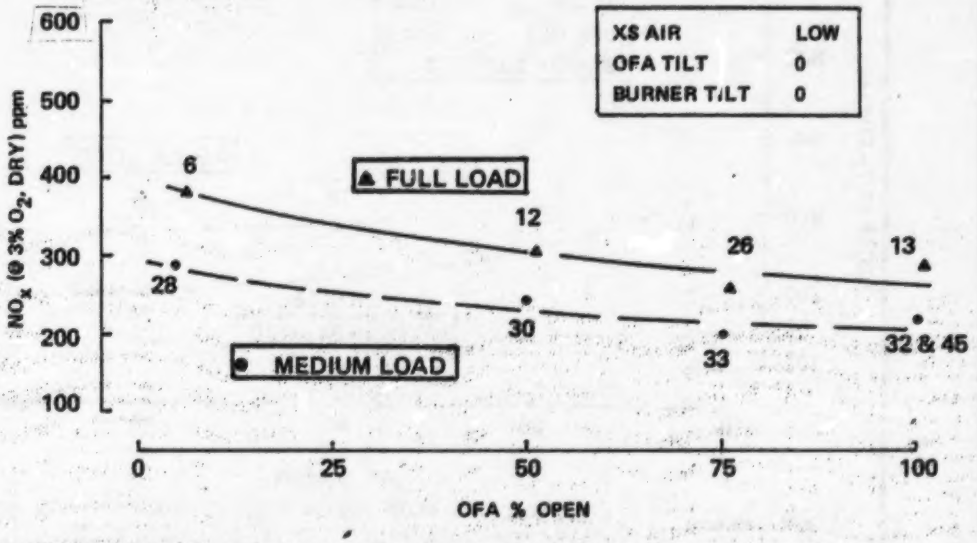

FIGURE B-III-11. NO$_x$ VS. OFA FLOW FOR DIFFERENT LOADS AT LOW EXCESS AIR, ZERO OFA TILT, AND ZERO BURNER TILT.

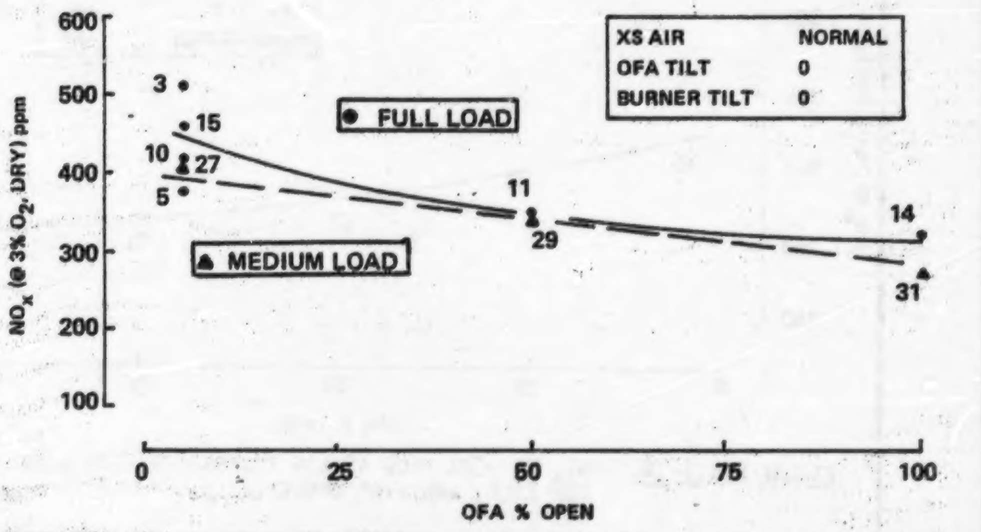

FIGURE B-III-12. NO$_x$ VS. OFA FLOW FOR DIFFERENT LOADS AT NORMAL EXCESS AIR, ZERO OFA TILT, AND ZERO BURNER TILT.

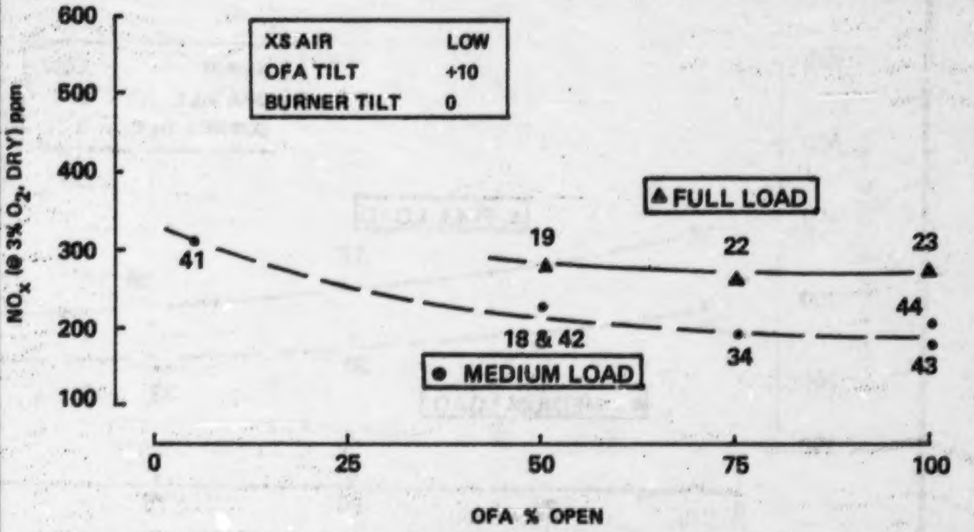

**FIGURE B-III-13.** NO$_X$ VS. OFA FLOW FOR DIFFERENT LOADS AT LOW EXCESS AIR, +10° OFA TILT, AND ZERO BURNER TILT.

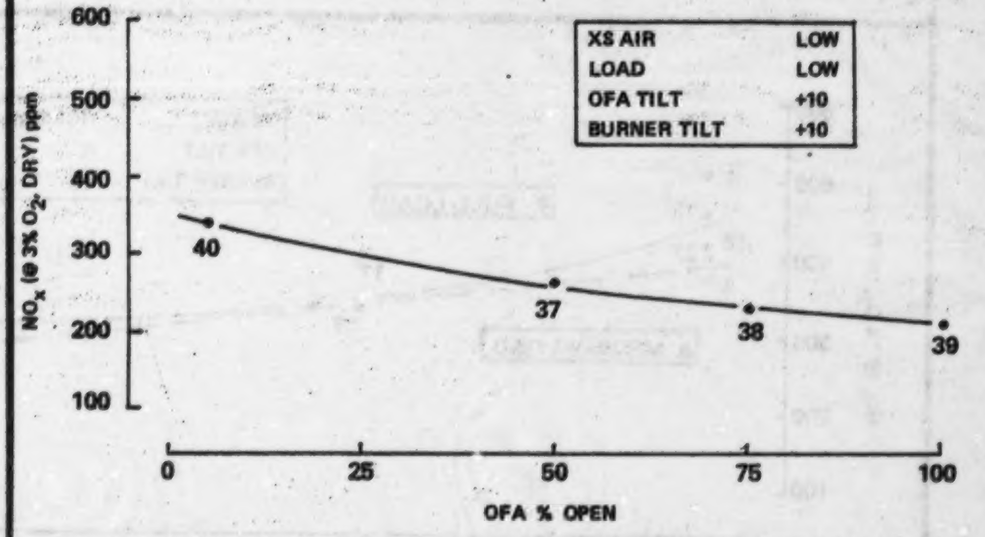

**FIGURE B-III-14.** NO$_X$ VS. OFA FLOW AT LOW EXCESS AIR, LOW LOAD, +10° OFA TILT, AND +10° BURNER TILT.

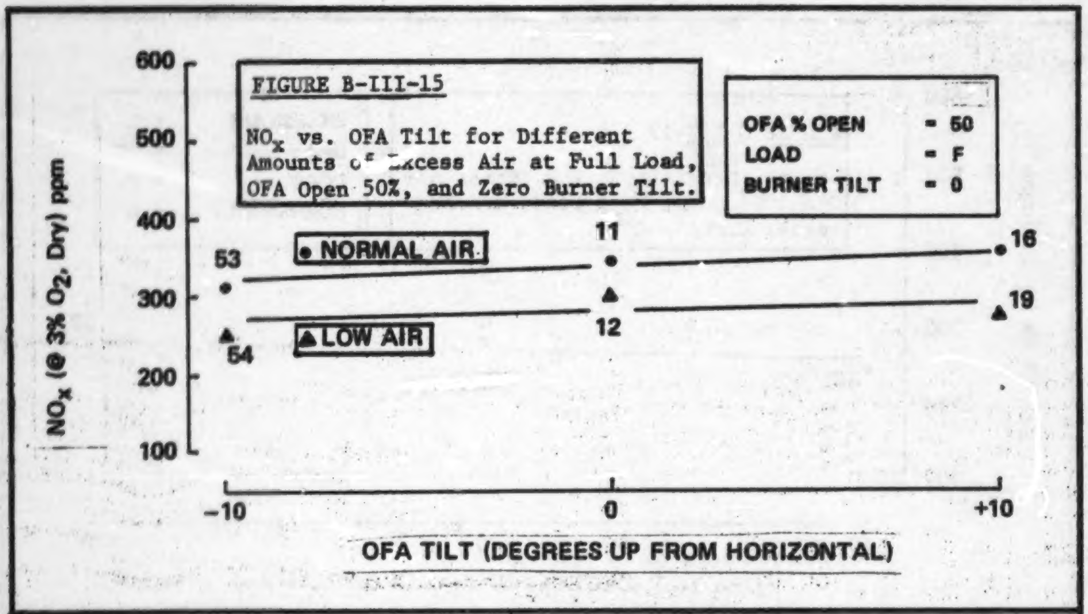

FIGURE B-III-15

$NO_x$ vs. OFA Tilt for Different Amounts of Excess Air at Full Load, OFA Open 50%, and Zero Burner Tilt.

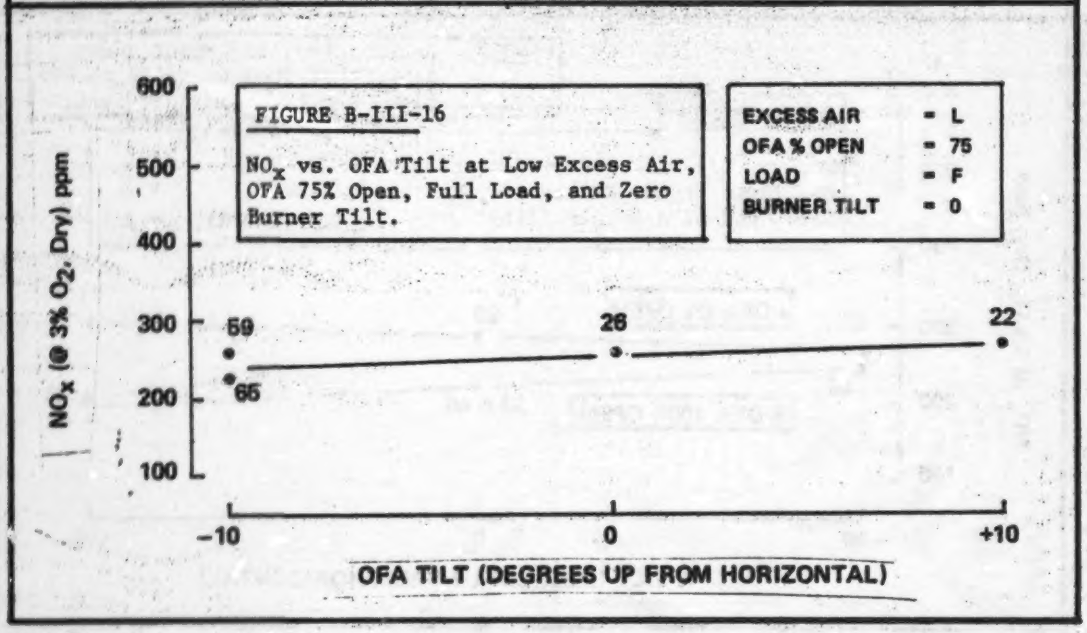

FIGURE B-III-16

$NO_x$ vs. OFA Tilt at Low Excess Air, OFA 75% Open, Full Load, and Zero Burner Tilt.

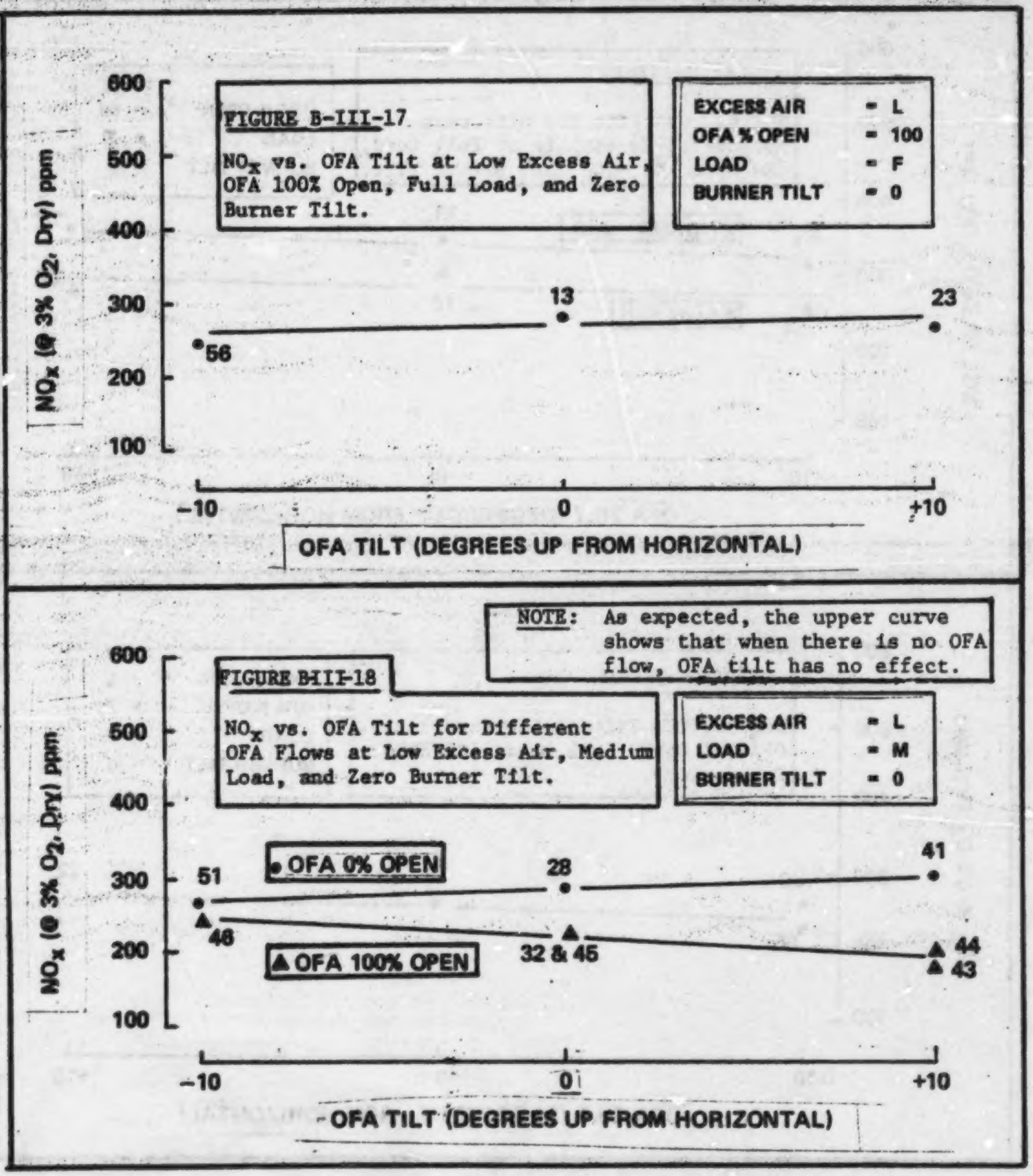

FIGURE B-III-17

$NO_x$ vs. OFA Tilt at Low Excess Air, OFA 100% Open, Full Load, and Zero Burner Tilt.

EXCESS AIR = L
OFA % OPEN = 100
LOAD = F
BURNER TILT = 0

FIGURE B-III-18

$NO_x$ vs. OFA Tilt for Different OFA Flows at Low Excess Air, Medium Load, and Zero Burner Tilt.

EXCESS AIR = L
LOAD = M
BURNER TILT = 0

NOTE: As expected, the upper curve shows that when there is no OFA flow, OFA tilt has no effect.

$NO_x$ VS. OVERFIRE AIR NOZZLE TILT
(TEST NUMBERS ARE SHOWN NEXT TO EACH DATA POINT)

pair exhibited in Figure B-III-15 clearly shows that $NO_x$ emissions decrease as excess air is decreased. Similarly, Figure B-III-18 shows that $NO_x$ emissions decrease as the OFA dampers are opened. Other families in the series show $NO_x$ decreasing with load. For example, compare Figure B-III-17 with the lower curve on Figure B-III-18.

This series of curves also shows $NO_x$ changing with OFA damper setting, but the effect is not strong. (Compare the lower curve on Figure B-III-15, Figure B-III-16, and Figure B-III-17.) These curves seem to indicate that the lowest (optimum) $NO_x$ emissions occur when the OFA is set at 75% open. This is supported by the "$NO_x$" vs. "OFA % Open" series of curves (Figures B-III-7 through B-III-12) which could easily be redrawn through the existing data to show a minimum near 75%. If this minimum truly exists, it is certainly a shallow minimum, and the effect is not strong. Of course, when the OFA dampers are nearly closed (OFA flow = 0), the OFA tilt is meaningless (see Figure B-III-18).

### 5. Other Influences on $NO_x$

In addition to the combustion parameters selected for this study, coal composition, burner tilt, and firing pattern (which burners are on) are also believed to affect $NO_x$ emissions. However, for this boiler there were not enough data gathered to establish those relationships.

During these tests, coal composition was relatively constant. Burner tilt was not under freedom of control, but rather had to be set according to steam temperature control requirements (usually horizontal). Firing pattern was not always controllable, but instead was determined by the plant maintenance schedule (mills shut down for overhaul, etc.). For most of the tests, all burners were on, and firing equally.

In order to simplify the data analysis, the possible effects of these (as well as unknown) influences on the data had to be factored out. Hence, careful attention was given to any operating parameter that may have changed from test to test.

## C. Furnace Gas Taps and Improved Operating Method

During two of the characterization tests (No. 64, and No. 65), furnace gas was sampled from locations shown on Figure B-II-4 and analyzed as described earlier in this report.

The purpose of these two tests was to study in detail, the effects of the improved operating method adopted by C&SOE after the joint recommendations of CE and ER&E, based on the characterization tests up to this point. The improved operating parameters are listed on Table B-III-4.

### TABLE B-III-4

### IMPROVED OPERATING PARAMETERS (SUMMARY CHART)

| Load (MW) | Mills in Service | $O_2$ % | OFA Dampers (% Open) FF | GG | OFA Tilts (Deg.) | Burner Tilts (Deg.) |
|---|---|---|---|---|---|---|
| Full (>400) | All | 3.5 | ← 75 → | | Up +10° | Horizontal or as necessary |
| 300-400 | A,B,C,D (Take E out Preferentially) | 3.5 | ← 75 → | | Up +10° | Horizontal or as necessary |
| 200-300 | Operate as usual | | ← 20 → | | Operate as usual | |
| <200 | | | | | | |
| Startup | | | | | | |
| Shutdown | | | | | | |
| Upset | | | | | | |

Test No. 64 (a "normal air" test) was done at excess air levels close to what was the norm before the improvements were adopted. Test No. 65 (a "low air" test) was done at air levels slightly lower than those recommended in the improved method. The results of tests 64 and 65 are shown in Tables B-III-6 through B-III-9, which include "as measured" values, as well as values "corrected to 3% $O_2$" dilution for the two tests. Results are discussed in Section IV.D of this part (Part B) of this report.

Table B-III-10 lists some of this available data in a form designed to coincide with the boiler geometry and physical layout of the sampling locations.

The table (B-III-10) can be used to identify the most corrosive local environments within the furnace, as well as how those environments change as total excess air is changed.

A summary of the gas tap data from these two tests (64 and 65) has been represented graphically on Figure B-III-19.

## D. $SO_2$-$SO_3$ Data (Flue Gas)

Three $SO_x$ tests (using wet chemistry) were run during the characterization tests. These were performed in conjunction with flue gas Test Nos. 16, 64, and 65, respectively, and represent concentrations upstream of the scrubber (between the air preheater and the scrubber). The following results were recorded.

TABLE B-III-5

$SO_2$ AND $SO_3$ IN THE FLUE GAS, UPSTREAM OF SCRUBBER (ppm)

| Test No. | Date | $SO_2$* (ppm) | $SO_3$* (ppm) | $O_2$** (%) |
|---|---|---|---|---|
| 16 | 1/24/79 | 2274 | 6.6 | 4.42 |
| 64 | 3/24/79 | 2585 | 14.3 | 4.82 |
| 65 | 3/25/79 | 2064 | 15.3 | 3.68 |

*Dry basis at actual oxygen concentration.

**The oxygen readings have been included here so that the reader may convert to other dilutions.

The ppm*** $SO_x$ emission rates may easily be corrected to 0.0% oxygen, 3% oxygen or some other dilution using standard methods. The EPA "F" factor method**** may then be applied for conversion to a mass emission rate per heat input basis.

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***ppm = parts per million

****The "F" factor tables list the volumes of dry undiluted flue gas produced per heating value of various fuels. Examples may be found in Appendixes D and F.

## TABLE B-III-6

## FURNACE GAS TAP TEST NO. 64 RESULTS AS MEASURED (DRY)

### Station - C&SOE Conesville Unit No. 5

| Gas Tap ID Number | $O_2$ (PCT) | $NO_x$ (CHEMI) (PPM) | NO (CHEMI) (PPM) | NO (NDIR) (PPM) | CO (PPM) | $CO_2$ (PCT) |
|---|---|---|---|---|---|---|
| 1 | 3.4 | 210. | 210. | 243. | 18956. | 14.71 |
| 2 | 5.4 | 180. | 170. | 207. | 18650. | 12.26 |
| 3 | 4.8 | 200. | 200. | 231. | 18650. | 13.95 |
| 4 | 6.5 | 180. | 180. | 213. | 18650. | 11.79 |
| 5 | 3.9 | 220. | 220. | 262. | 18650. | 14.20 |
| 6 | 6.4 | 190. | 190. | 231. | 18346. | 12.02 |
| 7 | 5.4 | 180. | 180. | 293. | 18650. | 11.79 |
| 8 | 5.0 | 190. | 190. | 231. | 18650. | 13.21 |
| 10 | 3.8 | 230. | 220. | 274. | 18650. | 14.46 |
| 11 | 9.0 | 150. | 140. | 102. | 18650. | 8.79 |
| 12 | 4.0 | 220. | 220. | 189. | 19887. | 14.20 |
| 13 | 10.0 | 140. | 130. | 130. | 18650. | 8.01 |
| 14 | 1.8 | 290. | 300. | 313. | 23134. | 15.77 |
| 15 | 7.0 | 180. | 180. | 201. | 18956. | 10.67 |
| 16 | 8.8 | 150. | 150. | 177. | 18650. | 9.20 |
| 17 | 14.6 | 70. | 70. | 102. | 18956. | 4.18 |
| 19 | 9.5 | 180. | 180. | 91. | 5947. | 9.20 |
| 23 | 11.5 | 150. | 130. | 74. | 5742. | 7.63 |
| 24 | 13.2 | 110. | 110. | 58. | 5742. | 5.82 |
| 25 | 10.6 | 130. | 130. | 63. | 5742. | 8.01 |
| 27: First Time | 9.8 | 180. | 170. | 85. | 6363. | 9.40 |
| 27: Second Time | 9.8 | 140. | 140. | 74. | 6363. | 7.44 |
| 28 | 9.1 | 140. | 130. | 69. | 6574. | 9.20 |
| 29 | 4.5 | 230. | 210. | 107. | 6786. | 13.70 |
| 30 | 5.8 | 200. | 200. | 91. | 6786. | 12.02 |
| 31 | 5.2 | 220. | 210. | 102. | 7000. | 13.95 |
| 32 | 10.6 | 160. | 140. | 74. | 6574. | 8.79 |
| 33 | 11.0 | 130. | 130. | 69. | 6574. | 8.60 |
| 34 | 3.4 | 230. | 220. | 102. | 6363. | 15.23 |
| 37: First Time | 4.5 | 240. | 230. | 136. | 6574. | 12.97 |
| 37: Second Time | 4.5 | 240. | 240. | 107. | 6786. | 14.46 |
| 36 | 1.7 | 280. | 270. | 124. | 12971. | 16.58 |
| 35 | 2.5 | 270. | 260. | 119. | 7000. | 15.77 |
| 38 | 2.9 | 250. | 240. | 113. | 6786. | 15.50 |
| Top of Hopper, Corner 3 (40) | 3.5 | 250. | 250. | 107. | 7875. | 14.71 |
| Top of Hopper, Corner 4 (41) | 3.2 | 250. | 250. | 147. | 7000. | 14.97 |
| Bottom of Hopper, Right Side | 7.5 | 170. | 160. | 80 | 6786. | 12.02 |

## TABLE B-III-7

## RESULTS CORRECTED TO 3% $O_2$ (DRY): FURNACE GAS TAP TEST NO. 64

C&SOE Conesville No. 5
3/24/80

| GAS TAP NO. | $O_2$ (MEAS) (PCT) | $NO_x$ (CHEMI) (PPM) | NO (CHEMI) (PPM) | NO (NDIR) (PPM) | CO (PPM) | $CO_2$ (PCT) |
|---|---|---|---|---|---|---|
| 1 | 3.4 | 215. | 215. | 249. | 19387. | 15.05 |
| 2 | 5.4 | 208. | 196. | 238. | 21519. | 14.41 |
| 3 | 4.8 | 222. | 222. | 257. | 20722. | 15.50 |
| 4 | 6.5 | 223. | 223. | 264. | 23151. | 14.64 |
| 5 | 3.9 | 232. | 232. | 276. | 19631. | 14.95 |
| 6 | 6.4 | 234. | 234. | 285. | 22618. | 14.82 |
| 7 | 5.4 | 208. | 208. | 338. | 21519. | 13.61 |
| 8 | 5.0 | 214. | 214. | 260. | 20981. | 14.86 |
| 10 | 3.8 | 241. | 230. | 287. | 19517. | 15.13 |
| 11 | 9.0 | 225. | 210. | 153. | 27975. | 13.19 |
| 12 | 4.0 | 233. | 233. | 200. | 21057. | 15.04 |
| 13 | 10.0 | 229. | 213. | 213. | 30518. | 13.11 |
| 14 | 1.8 | 272. | 281. | 293. | 21688. | 14.78 |
| 15 | 7.0 | 231. | 231. | 258. | 24372. | 13.72 |
| 16 | 8.8 | 221. | 221. | 261. | 27516. | 13.57 |
| 17 | 14.6 | 197. | 197. | 286. | 53313. | 11.74 |
| 19 | 9.5 | 282. | 282. | 142. | 9309. | 14.40 |
| 23 | 11.5 | 284. | 246. | 140. | 10880. | 14.45 |
| 24 | 13.2 | 254. | 254. | 133. | 13252. | 13.44 |
| 25 | 10.6 | 225. | 225. | 109. | 9939. | 13.86 |
| 27 First time, | 9.8 | 289. | 273. | 137. | 10226. | 15.11 |
| Second time | 9.8 | 225. | 225. | 119. | 10226. | 11.96 |
| 28 | 9.1 | 212. | 197. | 104. | 9943. | 13.91 |
| 29 | 4.5 | 251. | 229. | 117. | 7403. | 14.95 |
| 30 | 5.8 | 237. | 237. | 107. | 8036. | 14.24 |
| 31 | 5.2 | 251. | 239. | 116. | 7975. | 15.89 |
| 32 | 10.6 | 277. | 242. | 128. | 11377. | 15.22 |
| 33 | 11.0 | 234. | 234. | 124. | 11832. | 15.47 |
| 34 | 3.4 | 235. | 225. | 104. | 6508. | 15.58 |
| 37 First time, | 4.5 | 262. | 251. | 148. | 7171. | 14.15 |
| Second time | 4.5 | 262. | 262 | 117. | 7403. | 15.77 |
| 36 | 1.7 | 261. | 252. | 116. | 12097. | 15.47 |
| 35 | 2.5 | 263. | 253. | 116. | 6811. | 15.34 |
| 38 | 2.9 | 249. | 239. | 113. | 6748. | 15.41 |
| Top of Hopper, Corner 3 (40) | 3.5 | 257. | 257. | 111. | 8100. | 15.13 |
| Top of Hopper, Corner 4 (41) | 3.2 | 253. | 253. | 149. | 7079. | 15.14 |
| Bottom of Hopper, Right Side | 7.5 | 227. | 213. | 106. | 9048. | 16.03 |

## TABLE B-III-8

## FURNACE GAS TAP TEST NO. 65, RESULTS AS MEASURED (DRY)

C&SOE Conesville No. 5
3/25/80
Test No. 65

| | Gas Tap Identification | $O_2$ (PCT) | $NO_x$ (CHEMI) (PPM) | NO (CHEMI) (PPM) | NO (NDIR) (PPM) | CO (PPM) | $CO_2$ (PCT) |
|---|---|---|---|---|---|---|---|
| | Top of Hopper, Corner 3 (40) | 4.1 | 210. | 210. | 102. | 292. | 14.20 |
| | Bottom of Hopper, Right Side | 6.0 | 190. | 170. | 80. | 62. | 10.89 |
| | Top of Hopper, Corner 4 (41) | 5.0 | 200. | 210. | 89. | 330. | 12.73 |
| | Bottom of Hopper, Left Side | 7.0 | 130. | 140. | 80. | 340. | 10.67 |
| | Top of Hopper, Corner 2 (39) | 7.2 | 160. | 170. | 80. | 239. | 10.89 |
| | Top of Hopper, Corner 1 | 3.5 | 170. | 240. | 102. | 400. | 14.20 |
| | 38 | 3.0 | 200. | 200. | 113. | 239. | 15.23 |
| | 36 | 1.5 | 210. | 220. | 124. | 1096. | 15.50 |
| | 37 | 1.6 | 300. | 310. | 130. | 1062. | 16.58 |
| | 35 | 1.4 | 220. | 240. | 113. | 1062. | 16.86 |
| | 29 | 6.0 | 180. | 160. | 80. | 1182. | 11.34 |
| | 30 | 0.9 | 190. | 220. | 96. | 9244. | 17.14 |
| | 31 | 5.0 | 230. | 230. | 107. | 2009. | 12.26 |
| | 32 | 8.5 | 160. | 160. | 85. | 1344. | 8.60 |
| | 33 | 10.9 | 120. | 110. | 63. | 1344. | 7.44 |
| | 34 | 2.1 | 200. | 210. | 80. | 1508. | 15.23 |
| | 27 | 8.6 | 200. | 200. | 102. | 1841. | 9.20 |
| | 28 | 8.5 | 130. | 150. | 80. | 1841. | 8.60 |
| | 26 | 7.8 | 220. | 220. | 96. | 1841. | 9.40 |
| | 25 | 2.8 | 160. | 160. | 96. | 2180. | 14.71 |
| | 24 | 5.7 | 200. | 220. | 107. | 9955. | 13.21 |
| | 19 | 2.7 | 190. | 210. | 96. | ≥ 24842. | 13.95 |
| | 21 | 3.8 | 270. | 270. | 113. | 3238. | 13.21 |
| | 22 | 7.3 | 210. | 220. | 91. | 4744. | 10.67 |
| | 23 | 12.3 | 100. | 100. | 63. | 1673. | 5.82 |
| May be Mixed with Flue Gas | 1 | 1.6 | 220. | 220. | 96. | 3539. | 16.03 |
| | 2 (1st Time) | 17.0 | 20. | 20. | 26. | 549. | 0.43 |
| | 3 | 2.9 | 210. | 220. | 96. | 1021. | 14.97 |
| | 4 | 1.2 | 260. | 270. | 119. | 2009. | 16.86 |
| | 2 (2nd Time) | 1.7 | 180. | 160. | 85. | 10438. | 16.03 |
| | 5 | 3.0 | 170. | 170. | 80. | 8324. | 13.21 |
| | 6 | 3.1 | 170. | 180. | 91. | 1021. | 12.73 |
| | 7 | 4.7 | 180. | 190. | 96. | 862. | 13.70 |
| | 8 | 4.1 | 170. | 170. | 85. | 1021. | 14.20 |
| | 9 | 8.8 | 170. | 160. | 80. | 862. | 9.61 |
| | 10 | 2.3 | 170. | 180. | 85. | 13235. | 15.23 |
| | 11 | 0.6 | 70. | 70. | 32. | ≥ 25190. | 13.95 |
| | 12 | 7.0 | 150. | 160. | 85. | 1508. | 10.67 |
| | 13 | 2.0 | 310. | 310. | 142. | 4166. | 15.23 |
| | 14 | 3.8 | 180. | 220. | 113. | 4349. | 14.20 |
| | 15 | 5.0 | 230. | 230. | 113. | 2180. | 12.73 |
| | 16 | 7.0 | 160. | 190. | 96. | 1841. | 10.89 |
| | 17 | 10.0 | 140. | 140. | 80. | 1841. | 8.01 |

Burnerline

## TABLE B-III-9

## FURNACE GAS TAP TEST NO. 45, RESULTS CORRECTED TO 3% $O_2$ (DRY)

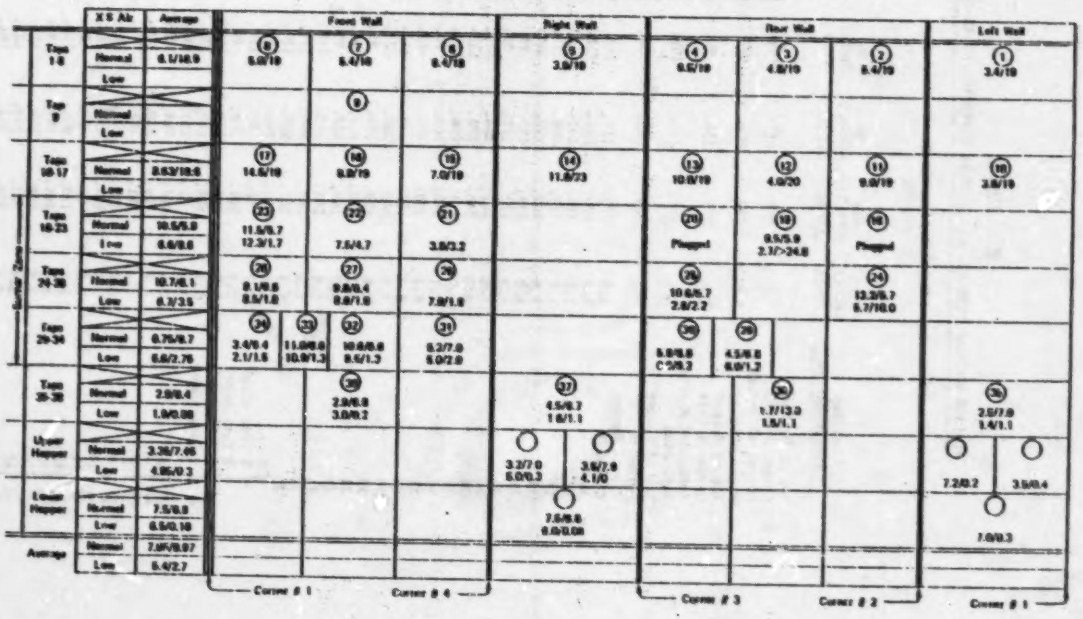
CSOE Conesville No. 5
3/25/80

| | Gas Tap Identification | $O_2$ (MSAS) (PCT) | $NO_x$ (CHEMI) (PPM) | NO (CHEMI) (PPM) | NO (NDIR) (PPM) | CO (PPM) | $CO_2$ (PCT) |
|---|---|---|---|---|---|---|---|
| | Top of Hopper Corner 3 (40) | 4.1 | 224. | 224. | 108. | 311. | 13.13 |
| | Bottom of Hopper Right side | 6.0 | 218. | 204. | 96. | 74. | 13.07 |
| | Top of Hopper Corner 4 (41) | 5.0 | 225. | 236. | 90. | 371. | 14.32 |
| | Bottom of Hopper Left side | 7.0 | 167. | 180. | 102. | 437. | 13.72 |
| | Top of Hopper Corner 2 (39) | 7.2 | 209. | 222. | 104. | 312. | 14.21 |
| | Top of Hopper Corner 1 | 3.3 | 175. | 247. | 105. | 411. | 14.61 |
| | 38 | 3.0 | 200. | 200. | 113. | 239. | 15.23 |
| | 36 | 1.3 | 194. | 203. | 115. | 1012. | 14.31 |
| | 37 | 1.6 | 278. | 288. | 121. | 985. | 15.39 |
| | 35 | 1.4 | 202. | 220. | 104. | 975. | 15.48 |
| | 29 | 6.0 | 216. | 192. | 96. | 1418. | 13.61 |
| | 30 | 0.9 | 170. | 197. | 86. | 8279. | 15.35 |
| | 31 | 5.0 | 281. | 259. | 121. | 2260. | 13.61 |
| | 32 | 8.5 | 230. | 230. | 123. | 1936. | 13.26 |
| | 33 | 10.9 | 214. | 196. | 113. | 2396. | 13.26 |
| | 34 | 2.1 | 190. | 200. | 76. | 1436. | 14.31 |
| | 27 | 8.6 | 290. | 290. | 148. | 2672. | 13.35 |
| | 28 | 8.3 | 187. | 216. | 115. | 2650. | 12.38 |
| | 26 | 7.8 | 300. | 300. | 131. | 2510. | 12.82 |
| | 25 | 2.8 | 158. | 158. | 95. | 2156. | 14.35 |
| | 24 | 3.7 | 235. | 239. | 126. | 11711. | 15.34 |
| | 19 | 2.7 | 187. | 207. | 95. | ≥ 24435. | 13.72 |
| | 21 | 3.8 | 283. | 283. | 118. | 3388. | 13.82 |
| | 22 | 7.3 | 280. | 293. | 121. | 6325. | 14.23 |
| | 23 | 12.3 | 207. | 207. | 131. | 3462. | 12.05 |
| May be Mixed With Flue Gas | 1 | 1.6 | 204. | 204. | 89. | 3139. | 14.88 |
| | 2 (1st time) | Possible Leak 17.0 | 90. | 90. | 115. | 2472. | 1.96 |
| | 3 (1st time) | 2.9 | 209. | 219. | 96. | 1016. | 14.89 |
| | 4 | 1.2 | 236. | 245. | 108. | 1827. | 15.33 |
| | 2 (2nd time) | 1.7 | 168. | 149. | 79. | 9735. | 14.95 |
| | 3 | 3.0 | 191. | 191. | 90. | 9365. | 14.86 |
| | 6 | 3.1 | 192. | 204. | 103. | 1136. | 14.41 |
| | 7 | 4.7 | 199. | 210. | 106. | 952. | 15.13 |
| | 8 | 4.1 | 181. | 181. | 91. | 1088. | 15.13 |
| | 9 | 8.8 | 251. | 236. | 117. | 1272. | 14.18 |
| | 10 | 2.3 | 184. | 173. | 82. | 12740. | 14.66 |
| | 11 | 0.6 | 62. | 62. | 46. | ≥ 22227. | 12.31 |
| | 12 | 7.0 | 193. | 206. | 109. | 1939. | 13.72 |
| | 13 | 2.0 | 284. | 294. | 134. | 3947. | 14.43 |
| | 14 | 3.8 | 188. | 230. | 118. | 4761. | 14.86 |
| | 15 | 5.0 | 281. | 259. | 127. | 2452. | 14.32 |
| | 16 | 7.0 | 206. | 244. | 124. | 2366. | 14.01 |
| | 17 | 10.0 | 229. | 229. | 130. | 3012. | 13.11 |

Table 8-III 16

FURNACE GAS TAP DATA, $O_2$ AND CO

(DRY) AS MEASURED RESULTS FROM TESTS 84 (NORMAL X-S AIR), AND # 85 (LOW X-S AIR)



## CO AND $O_2$ CONCENTRATIONS AS A FUNCTION OF HEIGHT IN THE FURNACE

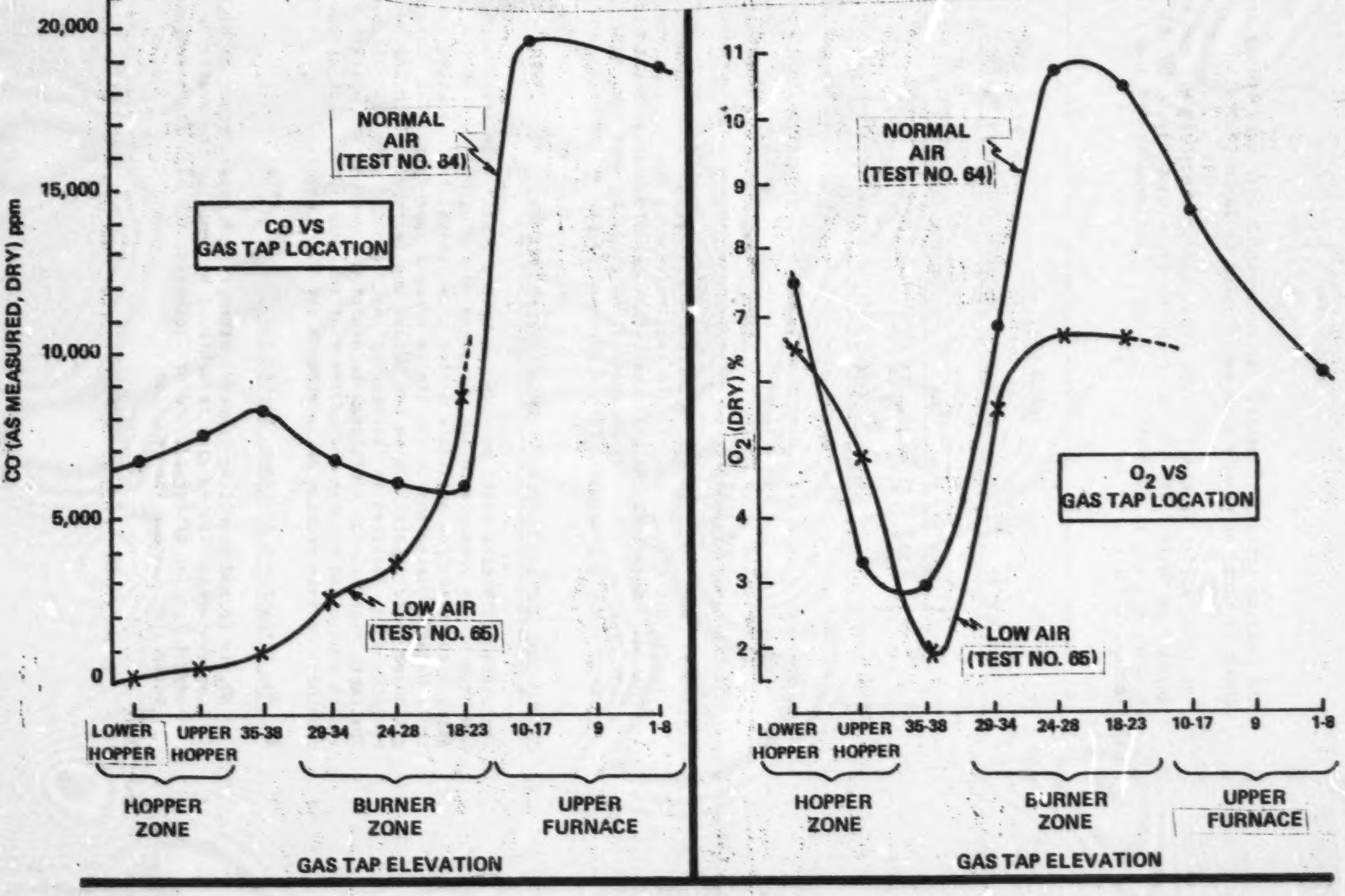


FIGURE B-III-19

GAS TAP TESTS SUMMARY

The results (after performing the conversions discussed above) are shown in terms of standard emission units in Table B-III-11.

The total sulfur in the flue gas (upstream of the scrubber) can be found from Table B-III-12, and from the facts that $SO_2$ is 50 wt% sulfur, and $SO_3$ is 40% sulfur by weight. The results are shown in Table B-III-11.

TABLE B-III-11

SULFUR IN FLUE GAS, UPSTREAM OF SCRUBBER (STANDARD UNITS)

| Test No. | Date | Sulfur (lb/MBtu) |
|---|---|---|
| 16 | 1/24/79 | 2.36 |
| 64 | 3/24/79 | 2.76 |
| 65 | 3/25/79 | 2.06 |

Comparison of the last columns of Tables B-III-13 and B-III-11 indicates that most of the coal-sulfur ends up in the flue gas. (This gas subsequently goes to the precipitator and scrubber where sulfur compounds are removed.)

A more detailed mass balance on sulfur (as well on other components) is possible through use of data gathered during the "Level 1" test that was conducted. In that test, flue gas flow rates, particulate flow rate, and elemental analysis of particulate were measured. The results are discussed in Part C of this report.

## IV. CONCLUSIONS AND DISCUSSION OF CHARACTERIZATION TESTS

The characterization tests provide one with a qualitative assessment of how this boiler responds to its operating controls. Because of the extra instrumentation available during these tests, the operating controls were evaluated beyond the limits normally possible. This investigation provided information to the boiler manufacturer and to the owner/operator which assisted in "setting up" and "tuning" this new boiler. The tests also provide additional information about how $NO_x$ emissions can be controlled through combustion modifications (CM). Most of the remainder of this section deals with CM for $NO_x$ control.

### A. $NO_x$ Formation & Abatement Mechanisms

$NO_x$ is formed when free (excess) nitrogen and oxygen react at high temperatures. Its control is achieved by removing the available oxygen (and/or nitrogen), and/or decreasing the high flame temperatures that sustain the reaction.

## TABLE B-III-12

## $SO_x$ IN FLUE GAS, UPSTREAM OF SCRUBBER (STANDARD UNITS)

| Test No. | Date | $SO_2$ | | $SO_3$ | |
|---|---|---|---|---|---|
| | | lb/MBtu | ng/J | lb/MBtu | ng/J |
| 16 | 1/24/79 | 4.70 | 2021 | 0.017 | 7.31 |
| 64 | 3/24/79 | 5.48 | 2355 | 0.038 | 16.32 |
| 65 | 3/25/79 | 4.09 | 1757 | 0.038 | 16.32 |

Coal analysis (Appendix B) shows that for Tests 64 and 65, the coal contains sulfur as follows:

## TABLE B-III-13

## SULFUR IN COAL

| Test No. | Btu/lb | Wt% Sulfur | (lb Sulfur)/(MBtu of Coal) |
|---|---|---|---|
| 16 | 10,625 | 3.8* | 3.58 |
| 64 | 12,271 | 4.52** | 3.68 |
| 65 | 11,993 | 4.76** | 3.97 |

Note: The last column is a calculated value equal to the second column divided by the first.

*From CE-KDL coal analysis
**From Exxon coal analysis

Oxygen concentration can be decreased by decreasing excess air flow. Alternatively, air flow may be selectively decreased in the vicinity of the ignition point so that highly reactive fuel-nitrogen released at the ignition point will lock onto molecules other than $O_2$ (such as other nitrogen molecules) and form products more desirable than $NO_x$ such as $N_2$. The remainder of the excess air may be added further downstream. This is known as staged combustion.

Flame temperature can be decreased by:

- o Increasing the size of the furnace. This provides more heat transfer surface area per pound of fuel burned, but is practical only during new construction and is of course not viable as a retrofit.

- o Staging the combustion process by adding air in small amounts as the fuel travels through the boiler. This causes the fuel to burn more slowly and thus give up its heat more slowly. (Staging also controls $NO_x$ by depriving the volatile nitrogen contained in the fuel of oxygen during its release in the initial stages of combustion. In the absence of $O_2$ this highly reactive nitrogen will lock onto other elements to form more desirable products before the addition of the remaining $O_2$ needed to complete the combustion process.) As indicated, staging is often desirable. However, not all boilers are capable of highly staged combustion on a routine basis.

- o Decreasing load. This works similarly to increasing the size of the furnace in that it results in a higher heat transfer area per heat input ratio, and thus, a cooler flame. However, load variation is determined by customer needs, and thus is not usually considered to be a viable method for $NO_x$ control.

## B. Recommended $NO_x$ Controls

Four combustion control parameters (each using one or more of the above principles) were selected for study as possible $NO_x$ controls. These were:

- o Total excess air flow
- o Overfire air flow
- o Overfire air nozzle tilt
- o Burner nozzle tilt

Except for burner tilt (which was constrained by steam temperature demand), the boiler operator was free to control each of these operating parameters, and a relationship was developed between each of these controls and $NO_x$ emissions. (Those relationships have been discussed in detail and are summarized on the next few pages.)

Other possible $NO_x$ controls on this boiler, not selected for routine use, because of the difficulty in manipulating them were:

- o Firing pattern
- o Load

It was concluded that on this boiler, $NO_x$ could routinely and most easily be controlled by adjusting:

1) Excess air flow
2) Overfire air flow
3) Overfire air tilt

Of these three, the first is most easily controlled, the second is computer controlled, and the third must be set manually (with considerable difficulty), and then left alone. These three parameters are discussed in Subsections 1, 2, and 3 below.

### 1. Decreased Excess Air Flow

$NO_x$ emissions continued to decrease as excess air was decreased. Too much decrease of excess air would cause CO emissions to suddenly climb steeply as a warning signal that more serious problems might develop if air flow continued to be decreased. Hence, a CO monitor proved to be a useful tool for determining the minimum safe excess air flow rate and is thus recommended for most new large boilers to assist in decreasing excess air to optimum low levels for $NO_x$ control.

### 2. Increased Overfire Air Flow

$NO_x$ emissions decreased as the overfire air dampers were opened, thus, redistributing the total air flow so that more of it entered the furnace above the burners. (This is a type of staging.) This was done without changing the total excess air flow. The effect was greatest as the dampers were opened to 50%. Beyond that, any further benefit was small.

Prior to these characterization tests, OFA had not been used on this boiler. However, as a result of this work, the computer control was changed to keep the OFA at 75% open most of the time.

### 3. Upward OFA Nozzle Tilt

Prior to these tests, it was felt that tilting the OFA nozzles upward would have the effect of "spreading out" the pseudo-staging effect of the OFA producing a cooler flame, and thus causing a decrease in $NO_x$ emissions. However, the tests revealed that this effect was very weak. In fact, in some cases, tilting the OFA nozzles up caused an increase in $NO_x$ emissions. More testing is needed to confirm these results.

## C. Sulfur Conversion

Approximately two thirds of the sulfur contained in the fuel was detected as $SO_2$ in the flue gas (upstream of the scrubber). For a more detailed sulfur balance, the interested reader is referred to Part C of this report, which covers the Level 1 test.

## D. Furnace Gas Analysis

Furnace gas composition did not seem to vary significantly along the walls at any particular elevation within the boiler. However, from elevation to elevation, certain trends were seen (see Figure B-III-19).

CO concentrations seemed lowest in the hopper elevations and climbed to a maximum just above the burner zone. Flue gas analysis indicates that final burnout (as evidenced by low CO readings) was always achieved upstream of the air heater.

$O_2$ concentrations were moderately high in the hopper region, decreasing to a minimum just below the burner zone, and climbed to a maximum near the top of the burner zone. By the time the flue gases reached the air heater, final burn out had occurred and the $O_2$ had been depleted to a low concentration probably by partially reacting with the CO (to form $CO_2$) which was also depleted in the process of final burn-out.

The regions with the most chemically reducing atmospheres (low $O_2$ and/or high CO concentrations) and therefore where local corrosion was expected to be most problematic, were in and around the burner zone. This was expected, and is related to actually measured corrosion later in this report.

## E. Improved Operating Procedure & Results

As a result of the characterization tests, ER&E and CE have recommended an improved operating procedure which C&SOE had agreed to try.

The improved procedure is load dependent, and involves decreased excess air flow rates and increased OFA flow. The procedure is summarized on Table B-III-4.

Prior to this test program, typical full load (as found) $NO_x$ emissions (corrected to 3% $O_2$, dry basis) were 446 ppm (average of Tests 3, 5, 10 and 15). This corresponds to 0.61 lb/MBtu (263 ng/J) as equivalent $NO_2$, and is well within the applicable NSPS limit of 0.7 lb/MBtu (301 ng/J).

By opening the OFA dampers to about 75% and decreasing the excess air to the limit of safety and controllability, $NO_x$ emissions (corrected to 3% $O_2$, dry) were decreased to about 260 ppm (Test 26). This corresponds to 0.35 lb/MBtu (152 ng/J), and represents a decrease in $NO_x$ emissions to less than 60% of the "as-found" (Tests 3, 5, 10, and 15) values. Tests 13, 22, 23, 56, and 59, run under conditions similar to those of test No. 26, give similar results.

This decrease of $NO_x$ emissions at the most frequently encountered load and boiler operating condition, occurred with no observed adverse short-term side effects. (Long-term side effects such as water-wall corrosion, are discussed in Part D of this report.)

# PART C

# LEVEL 1 ENVIRONMENTAL ASSESSMENT

## I. PURPOSE AND OPERATING CONDITIONS FOR THE LEVEL 1 TEST

This section describes a Level 1 environmental assessment screening study of combustion modifications (CM) for $NO_x$ control on a utility boiler designed and operated for compliance with the applicable New Source Performance Standard (NSPS) for emissions of nitrogen oxides ($NO_x$) while burning high-sulfur coal. The standard that applies is 0.7 pounds of $NO_x$ (as $NO_2$) per million Btu* of heat input (301 ng/J). Certain streams are assumed not to be affected by such modifications, and therefore were not sampled. (The sampling procedure is discussed later in this report.)

### A. Purpose of the Level 1 Test

The Level 1 testing procedure developed by the EPA provides for the rough assessment of a wide variety of process emissions. It is the first in a three-phase approach designed to evaluate emissions from a point source.

The Level 1 procedures developed by the Process Measurement Branch (PMB) of EPA's Industrial Environmental Research Laboratory (IERL)** encompass all effluent streams from a process - which in this case is the Conesville No. 5 boiler. However in this case, the only streams sampled were those thought to be affected by modifications for "low-$NO_x$" combustion. Some inlet streams were also sampled so that a mass balance could be performed on the plant, and in order to separate out process emissions from those due to the inlet streams. This helped to determine how the inlet streams are changed chemically by the process and redistributed to the various outlet streams.

This test, according to the EPA Level 1 procedures manual, was designed to quantify emissions within an accuracy factor of 3, while answering the following questions:

- o What pollutants are being emitted?
- o What effluent streams are toxic?
- o How toxic are those streams?
- o What is the mass emission rate of each pollutant?

These questions were answered through sampling and analysis of pertinent effluent streams: solid, liquid, gaseous and particulate. Analysis was physical, chemical and biological.

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*Btu = British Thermal Unit.

**"IERL-RTP Procedures Manual: Level 1 Environmental Assessment (second edition)." EPA-600/7-78-201, October, 1978.

## B. Operating Conditions During the Level 1 Test

This test was an evaluation of optimized NSPS operation of this boiler following the characterization testing described earlier. No unusual operating conditions were established for this test other than the new standard operating procedure which resulted from the characterization tests.* The test conditions are summarized in Table C-I-1. (Details may be found in Appendix A.)

**TABLE C-I-1**

**SUMMARY OF BOILER OPERATING CONDITIONS**

| | | |
|---|---|---|
| Load (electric output): | 408 | MW |
| Steam Flow (production): | 2,900,000 | pounds/hour |
| Steam Pressure: | 2400 | psig |
| Steam Temperature: | 980 | °F |
| Fuel Consumption (coal): | 360,000 | pounds/hr |
| Burners on: | B,C,D,&E Mills | (only "A" mill is off) |
| Overfire Air Dampers | | 70% of full open |
| Overfire Air Tilt (up is positive) | | -12 degrees* |
| Burner Tilt (up is positive) | | 0 deg at start of test,<br>-14 deg by end of test |
| Excess Air | | Normal (as optimized) |
| Heat Input Rate | | 4,450 MBtu/Hr** |

Conesville No. 5 is capable of full load when using only 16 of its 20 burners. When not needed, the burners to be shut down are chosen arbitrarily. For this test, the boiler operator chose to shut down the four burners (one in each corner) on the bottom-most elevation ("A"). Although this is not necessarily the best*** selection for decreased $NO_x$ emissions, it is typical of normal operation of this boiler.

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*Although a positive OFA tilt was recommended (Part B of this report), it was not achieved for this test (possibly due to a jammed servo). However, as explained earlier, the effect of OFA tilt is small, and was not expected to significantly affect the results.

**A post-test calculation based on the "F" factor method (from Entropy's report (discussed later in this report - see Appendix F) gives 4,637 MBtu/Hr, while another type of post-test calculation (included in Appendix D) based on fuel feed rate and ER&E's analysis of Btu content of coal yields 4,263 MBtu/Hr. The value used here is the average of the two methods.

***Testing under previous programs (e.g., EPA Contract 68-02-1415) shows that $NO_x$ emissions can be decreased on some boilers by shutting off the fuel feeding the top burner elevation and feeding only air at this elevation. In this way, the top burners become a source of overfire air.

## II. SAMPLING PROCEDURES

The Level 1 procedures were modified so that the only effluent streams sampled were those thought to be affected by "low-$NO_x$" operation. Some inlet streams were also sampled in order to allow incoming contaminants to be factored out.

Table C-II-1 lists the various sampling points with reference to Figure C-II-1 which shows the general layout of the boiler tested. Sampling was performed on September 10, 1980, and generaly followed the procedures listed in the EPA Level 1 procedures manual*.

Concurrently, complimentary testing was performed by Acurex Corporation under a separate contract with the EPA as discussed later in this report. ER&E and Acurex have exchanged data to minimize costs to the EPA.

### A. Flue Gas at Boiler Exit (Economizer Outlet)

#### 1. Continuous Monitors (Permanent Gases)

Flue gas was analyzed as described in Part B of this report. Particulate matter and water were removed from the flue gas by filters and permeation tube dryers, respectively. The samples were then cooled and pumped through "Polyflo" brand plastic tubing to a mobile laboratory containing the continuous gas analyzers. Typically, only the "permanent" gases ($O_2$, $CO_2$, etc.) and major pollutants ($NO_x$, CO, etc.) were analyzed in this way. Other gases (as well as the permanent gases) were analyzed by gas chromatography (GC).

#### 2. Gas Chromatography

Gas chromatography (GC) was used to detect the most difficult-to-analyze flue gases. All on-site GC field work was done on a three-detector Perkin-Elmer model Sigma 2(B) gas chromatograph with a Spectra-Physics SP-4100 computing integrator.

GC analysis was generally performed according to the procedures outlined in the Level 1 manual*. Gas samples were taken from the flue duct (just upstream of the air heater) in a glass sampling vessel designed for GC grab samples. After sampling, the vessel was taken to the GC where, a few minutes later, a sample was removed from it (by syringe) and injected into the GC for analysis.

All columns were supplied by Supelco company, and all calibration gases except for the hydrocarbon standard mixture (which was supplied by Scott Co.) were supplied by Matheson Company.

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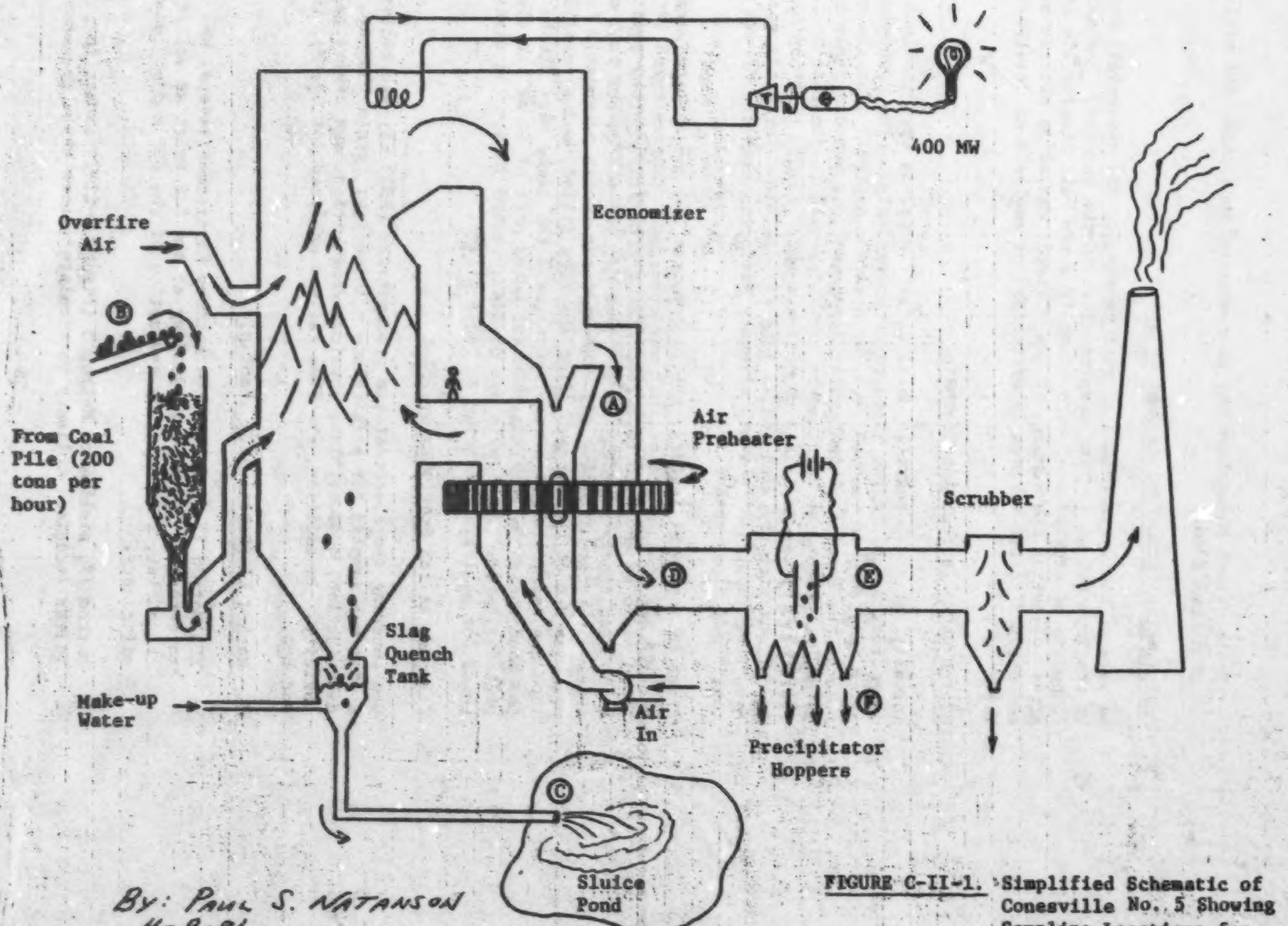
*"IERL-RTP Procedures Manual: Level 1 Environmental Assessment (second edition)." EPA - 600/7-78-201, October, 1978.

## TABLE C-II-1

### SAMPLES TAKEN BY ER&E FOR LEVEL 1 ANALYSIS

| | Sample* | Analysis |
|---|---|---|
| A | Flue Gas (as it leaves the furnace) | $O_2$, CO, $CO_2$, $H_2$, $N_2$, hydrocarbons, cyanide derivatives, sulfur-complexes, ammonia type compounds, oxides of nitrogen |
| B | Coal Belt (7 hours before being burned - as fired) | Proximate, ultimate, sulfur, heat content, bio-assay |
| C | Sluice water from quench tank (ash leachate) | Chemical assay, bio-assay |
| D | Flue Gas (at ESP inlet) | Particulate loading & size distribution, organic and inorganics, condensibles, trace elements, bio-assay |
| E | Flue Gas (at ESP outlet) | Particulate loading |
| F | Fly ash (at ESP hopper) | Chemical assay, bio-assay |

*See Figure C-II-1.



By: Paul S. Natanson
4-9-81

**FIGURE C-II-1.** Simplified Schematic of Conesville No. 5 Showing Sampling Locations for Level 1 Testing. (See Table C-II-1 for key).

Table C-II-2 summarizes the GC operating conditions and calibration standards.

## B. Fuel Samples (from Feed to Coal Silos)

Because of the large volume of coal needed for the biological tests, it was impractical to take samples close to the burners. Instead, 75 pounds of crushed coal were taken from the belt feeding the silos. After collecting the sample, it was divided, sealed in plastic bags, and shipped to the various laboratories for analysis as described on Table C-II-3.

## C. Sluice Water (Bottom-Ash Leachate)

Normally, at the Conesville No. 5 boiler, water is used to flush slag (bottom ash) to the waste pond continuously. (The precipitator catch (fly ash) is removed, dry, by a vacuum system.) For the purpose of the Level 1 environmental assessment, it was desirable to know what effect the slag had on the water used to flush it out. Therefore, it was desirable to obtain a water sample that had been in contact with the slag for as long as possible. Hence the slag hopper was operated in a way slightly different from the normal continuous flush method.

Prior to the Level 1 tests, the slag hopper and quench tank were emptied and cleaned out so that any subsequent samples taken from there would be known to be a result of the test. Once the test began, the discharge gates were closed off and the quench tank was allowed to fill with slag and make-up water (which presumably leached solubles out of the slag). After the tank filled, and several hours into the test, the gates were opened, and the tanks were flushed to the pond where the sampling team collected part of it at the sluice pipe discharge. The sample was divided, packed in ice and distributed for analysis according to Table C-II-4.

## D. Flue Gas at the Precipitator Inlet

Gas entering the electrostatic precipitator (ESP) fly ash removal system was sampled for particulate - including: grain loading, size distribution, condensibles, chemical composition, and biological toxicity. In addition, the flue gas was analyzed for $O_2$, $N_2$, $CO_2$, and $H_2O$.

### 1. Method 17 (Particulate Loading)

EPA Method 17 (performed by Entropy Environmentalists) was used to determine particulate loading at the ESP inlet as well as at the outlet, thus allowing evaluation of the ESP's dust removal efficiency.

Method 17, similar to Method 5 (Figure C-II-2) except for the filter location, collects particulate matter while traversing

## TABLE C-II-2

## GAS CHROMATOGRAPHY SPECIFICATIONS

| Method | Species of Interest | Calibration Standard* | Column | Temperature & Conditions | Detector |
|---|---|---|---|---|---|
| A | CO<br>$CO_2$<br>$O_2$<br>$H_2$<br>$CH_4$<br>$N_2$ | 166 ppm }<br>13.3% }<br>3.78% } *<br>0.97% }<br>26 ppm }<br>Balance } | Carbosieve S<br>7' x 1/8" SS<br>100/120 mesh<br>size | 35°C for 4 min.,<br>then 25°C/min.<br>to 175°C.<br>40 cc/min.<br>Inject 1 cc | Dual<br>TCD<br>(HWD) |
| B | $H_2S$<br>$SO_2$<br>COS<br>Thiophene<br>Methyl Mercaptan<br>Ethyl Mercaptan | 1.5 ppm *<br>2123 ppm }<br>5 ppm }<br>1.8 ppm } *<br>0.96 ppm }<br>0.92 ppm } | 36' x 1/8" (OD)<br>Teflon with<br>12% polyphenyl<br>ether and 0.5%<br>$H_3PO_4$ on 40/60<br>mesh Chromosorb T | 50°C for 5 min.<br>then 10°C/min.<br>to 100°C | Single FPD |
| C | $NH_3$<br>HCN<br>Cyanogen | 190 ppm *<br>130 ppm } *<br>170 ppm } | 6' x 1/4" (OD),<br>x 2 mm (ID)<br>Glass with 60/80<br>mesh Poropak Q | 40°C<br>Isothermal | Dual<br>TCD<br>(HWD) |
| D | Light Hydrocarbons<br>$C_1 - C_5$ | Methane 15.1 ppm }<br>Ethane 14.8 ppm }<br>Propane 15.7 ppm }<br>Butane 15.2 ppm } *<br>Pentane 16.2 ppm }<br>Hexane 17.1 ppm }<br>Heptane 13.1 ppm } | 6' x 1/4" (OD),<br>x 2 mm (ID)<br>Glass w/ 60/80<br>mesh Poropak Q | 60°C for 4 min.,<br>then 20°C/min.<br>to 110°C.<br>Inject 1 cc | Single FID |
| E | Heavy Hydrocarbons<br>$C_1 - C_7$ |  | 6' x 1/4" (OD),<br>x 2 mm (ID)<br>Glass w/ 20%<br>SP 2100 on 80/100<br>mesh Supelcoport | Isothermal @ 30°C. | Single FID |

**Notes:**

In all cases, the carrier gas was helium.

*Brackets indicate a single blend in one cylinder with nitrogen making up the balance.

## TABLE C-II-3

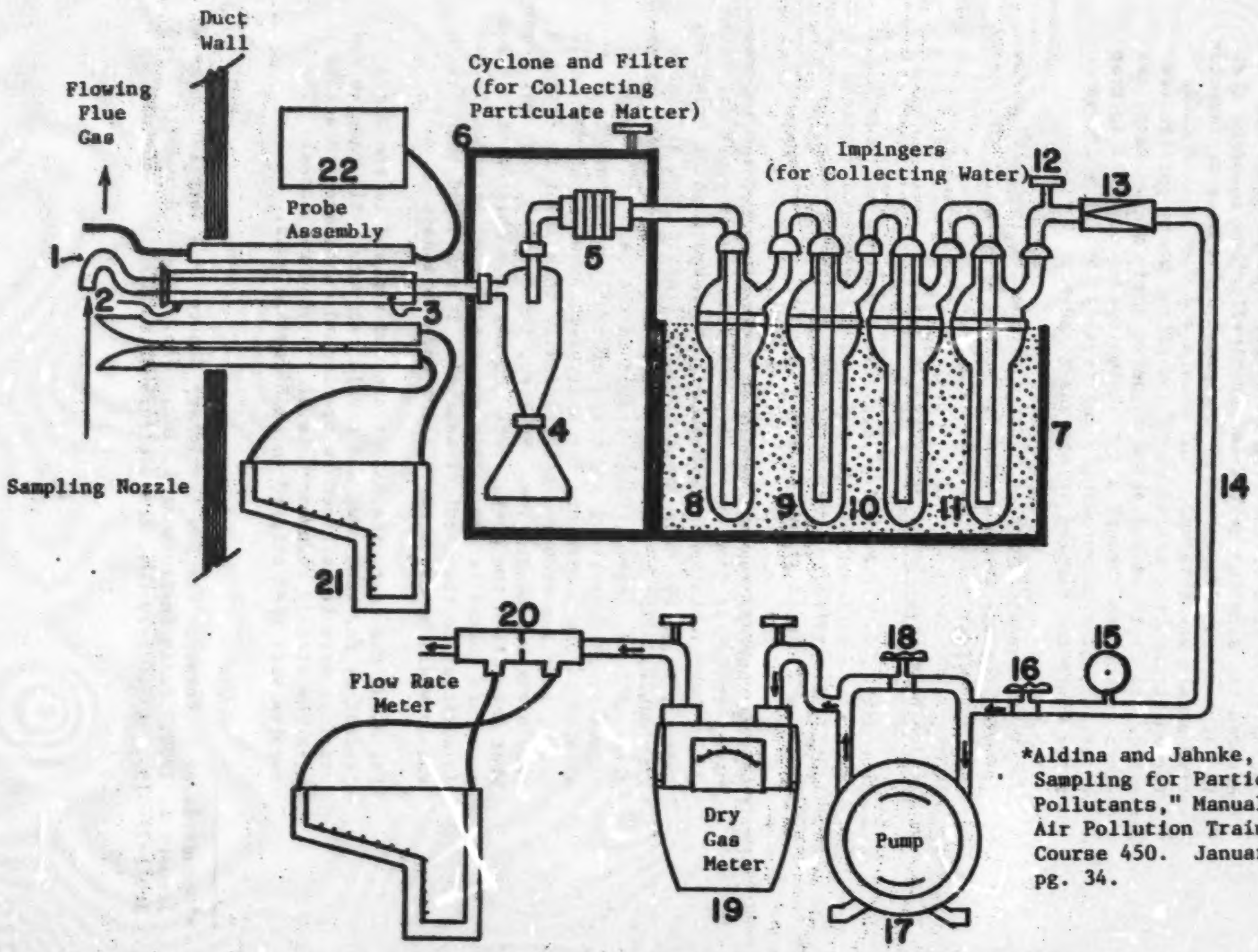
## COAL SAMPLE DISTRIBUTION AND ANALYSIS

| Laboratory | Analysis |
|---|---|
| Battelle Labs (60 pounds) | Biological assay using aquatic life forms |
| Research Triangle Institute (RTI) (2 pounds) | Biological assay using land animals |
| Exxon, Baytown (2 pounds) | Physical analysis such as proximate and ultimate analysis including sulfur, nitrogen, moisture, ash, ash fusion temperature, heat content, and other standard ASTM tests |
| ER&E, Linden (2 pounds) | Chemical analysis |

## TABLE C-II-4

## SLUICE WATER DISTRIBUTION & ANALYSIS

| Laboratory | Analysis |
|---|---|
| Battelle Columbus Laboratories (25 gallons) | Biological assay using aquatic life forms |
| Research Triangle Institute (1 gallon) | Biological assay using land animals |
| ER&E, Linden (1 gallon) | Chemical analysis |



*Aldina and Jahnke, "Source Sampling for Particulate Pollutants," Manual: US EPA Air Pollution Training Institute-Course 450. January, 1978, pg. 34.

Figure C-II-2. EPA Method 5 Particulate Sampling Train*.

the gas stream. (A full description of Method 17 and other EPA methods may be found in the "Standards of Performance for New Stationary Sources."*)

During a traverse of the flue duct, particulate-laden gas entered the sampling nozzle isokinetically thus assuring that the stream was undisturbed by the probe and that a representative sample was obtained. The sample was then pulled under vacuum through the heated probe and filter where particulate matter was captured and saved to be weighed later. Next, the clean gas passed through a set of impingers (designed to trap water for later measurement), and finally through a dry gas meter where the sampled volume was measured.

The total concentration of particulate matter in the flue gas entering the precipitator was determined by weighing the "catch" on the in-stack Method 17 filter.

## 2. Source Assessment Sampling System (SASS)

In addition to the Method 17 traverse (multi-point) sampling of particulate matter, a single-point sample was also obtained (by "SASS") according to EPA procedures. (A schematic of the SASS train is shown in Figure C-II-3.)

Because the SASS takes a sample at a single point, the information provided by SASS on total particulate loading may not be as good as that obtained by a Method 5 or 17 multi-point traverse. However, it (SASS) does yield other information not available from methods 5 or 17, including size distribution of the particles, in four ranges. Other stages in the SASS train capture organics, condensables, and trace elements which were then shipped to the laboratory for analysis. As with the Method 17 train, sampling occurred isokinetically thus assuring that the sample was representative. However, the sampling rate was somewhat lower than the design rate and may have shifted the cyclone cutpoints toward larger particles as explained in Appendix H. In addition to the chemical analysis, it was hoped that enough sample would be captured to allow for bio-assays as well.

Following the test, the SASS train was removed to the field laboratory for wash-down and sample recovery. All samples and washings were transferred to precleaned containers in accord with the already referenced Level 1 procedures manual. The samples were then shipped to ER&E for analysis.

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*"Standards of Performance for New Stationary Sources - A Compilation as of January 1, 1980," Pedco Environmental, Inc. Jan. '80. EPA numbers: EPA 340/1-77-015, EPA 340/1-79-001, EPA 340/1-79-001a, EPA 340/1-80-001.

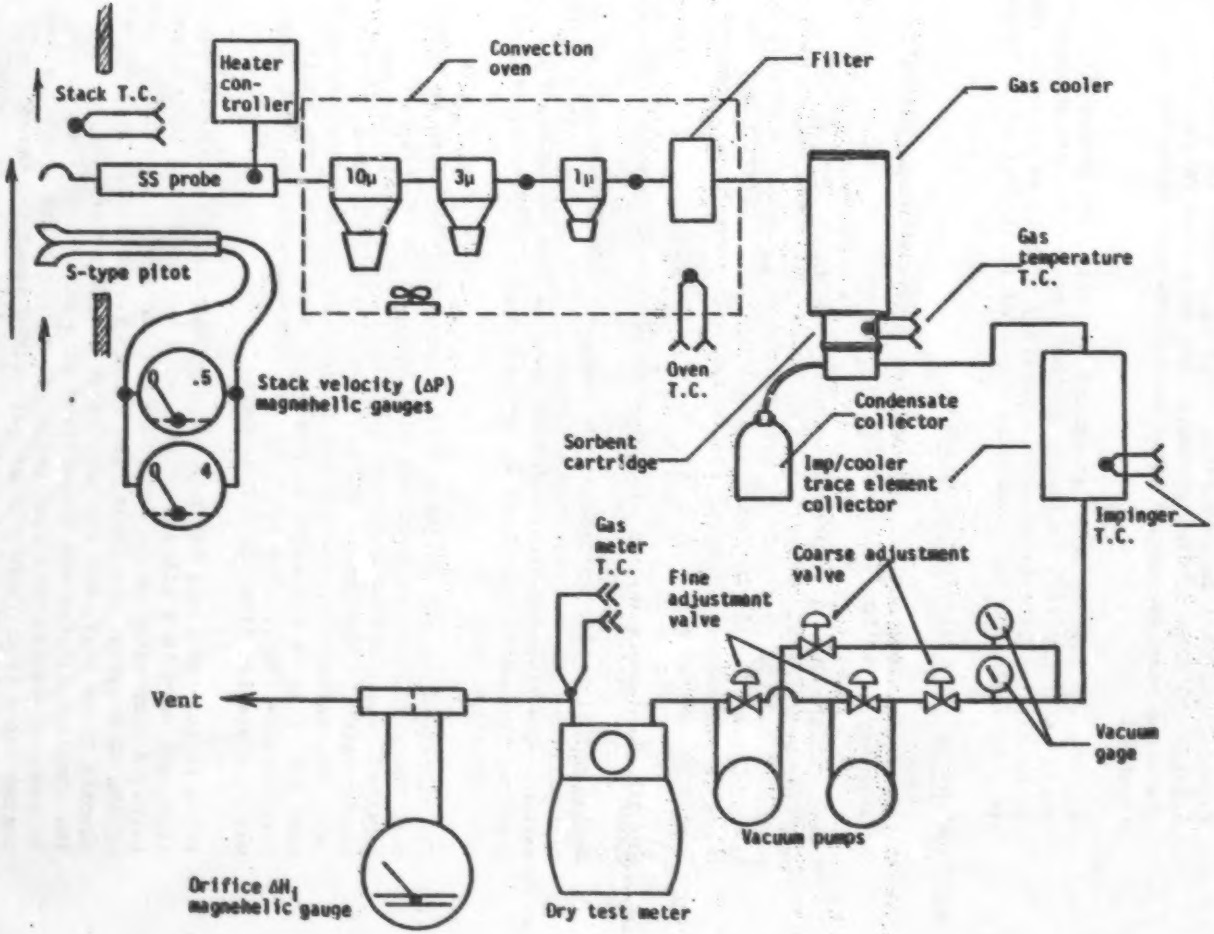

Figure C-II-3. Schematic of SASS*

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*D. E. Blake, "Source Assessment Sampling System: Design and Development," U.S. Environmental Protection Agency Publication #EPA-600/7-78-018, February, 1978, pg. 4-5.

### 3. $O_2$, CO, $CO_2$, $N_2$, and $H_2O$ Determination

Calculations used in isokinetic sampling require information concerning the temperature, pressure, and molecular weight of the gas being sampled. Hence these parameters were measured and recorded.

$O_2$, CO, $CO_2$, and $N_2$ were determined by Orsat (EPA Method 3), while water content, initially assumed (as per EPA procedures) to be 8%, was determined more accurately a short while after the test by measuring the condensate captured in the Method 17 train.

## E. Flue Gas At The Precipitator Outlet

At the precipitator outlet, sampling and analysis was performed in the same way as at the inlet (discussed earlier).

Except for the Method 17 particulate loading tests, most of the sampling here (SASS, controlled condensation train for sulfur compounds, etc.) was performed as part of the supplemental test work by Acurex Corp. and will be reported independently. However, for the reader's convenience, some of that data is included in this report (see Appendix I).

## F. Fly Ash

During normal boiler operation, the heaviest ash (bottom ash) eventually falls into the slag hopper (quench tank) at the bottom of the boiler. The lighter, finer ash (fly ash) is carried by the flue gases as fly ash to the clean-up systems (e.g., ESP) downstream of the combustion zone.

The stickiest fly ash (highest sulfur content — based on independent Exxon studies) is believed to deposit on the superheater and reheater tube plattens and eventually falls into the economizer hopper which is thought to collect less than 10% of the total fly ash. The majority of the fly ash is carried downstream where more than 90% of it is collected in the hoppers of the electrostatic precipitator (ESP). The only fly ash referred to in this section was that sampled from the ESP hoppers.

Prior to the test, all ESP hoppers (approximately forty) were emptied, and were then allowed to fill with ash generated during the test. A composite sample was collected consisting of ash from most of the 40 hoppers. At first, the sample was collected in ordinary plastic trash bags, but the hot, heavy sample melted the bags, so the sample collected was transferred into cardboard fiber drums. Subsequent samples were also collected in cardboard drums and transferred later to a plastic-lined galvanized steel tub where the sample was allowed to cool outdoors overnight. The next morning, the 75 pounds of fly ash sample was mixed by hand, and sealed in brown plastic bags for shipping. The distribution of the sample is summarized in Table C-II-5.

TABLE C-II-5

FLY ASH DISTRIBUTION AND ANALYSIS

| Laboratory | Analysis |
|---|---|
| Battelle Columbus Laboratories (60 pounds) | Biological assay using aquatic life forms |
| Research Triangle Institute (2 pounds) | Biological assay using land animals |
| Exxon, Baytown (2 pounds) | Physical and chemical analysis |
| ER&E, Linden (2 pounds) | Chemicals analysis |

## III. ANALYTICAL PROCEDURES

Generally, sample analysis (some of which has already been discussed) was carried out according to the already referenced EPA Level 1 procedures manual. Exceptions are noted in the individual sections that follow.

Using the continuous monitors described in Part B of this report, the gaseous phase of the flue stream leaving the boiler was the only sample analyzed in the field. All other samples were shipped to various laboratories for analysis. For the sluice water, pH and temperature were measured in the field prior to shipping.

## IV. RESULTS OF LEVEL 1 ENVIRONMENTAL ASSESSMENT TEST

### A. Flue Gas Leaving The Boiler

#### 1. Continuous Monitors

Most of the sample collecting activities related to this Level 1 test were accomplished in approximately twelve hours. For about twenty minutes of each hour, flue gas samples (from between the economizer and air heater) were analyzed by continuous monitors. The results averaged over the test period are presented in Table C-IV-1. More detailed results of flue gas Level 1 analysis may be found in Appendix C.

TABLE C-IV-1

ER&E'S FLUE DUCT GAS ANALYSIS (DRY)
(Avg. for 12:13 - 21:46 on 9-10-80)

| $O_2$ | $NO_x$ | NO | CO | $CO_2$ |
|---|---|---|---|---|
| (%)<br>(dry) | ppm<br>(corrected to 3% $O_2$, dry basis) | ppm | ppm | % |
| 5.42* | 337 | 332 | 24 | 15.2 |

*Control room $O_2$ instrument averaged 4.0 for this period.

## 2. Gas Chromatography

Flue gas analysis by gas chromatography (GC) proved to be much more difficult than expected. Problems with calibration of the various columns and detectors were perhaps the most difficult obstacles.

Calibration gases (many containing less than 100 ppm of the specie of interest) had been prepared and bottled offsite a few months prior to this test. The small concentrations involved may have reacted in the cylinder, or been adsorbed by the cylinder walls before the test, and may thus explain why some of the calibration species could not be detected by the GC. Consequently, a new procedure was adopted which involves the on-site preparation of low concentration calibration gases on an "as-needed, when-needed" basis.

Operational difficulties with the sensitive GC detector prevented nitrogen-compound analysis by GC. A summary of significant GC results appears in Table C-IV-2. Details are included in Appendix E.

## TABLE C-IV-2

## GC RESULTS (FLUE GAS AT ECONOMIZER OUTLET)

| Analytical Method (From Table C-II-2) | Component | Response Factor** (Peak Area Units / Unit of Concentration) | Concentration in Flue Gas |
|---|---|---|---|
| A<br>PERMANENT GASES | $H_2$ | 123-1890/percent | Possibly present |
| | $O_2$ | 60,000-195,300/percent | Present |
| | $N_2$ | 62,000-157,000/percent | Present |
| | CO | Calibration gas not detected | Trace |
| | $H_2O$ | Interference | Present |
| | $CO_2$ | 213,700-270,100/percent | Present |
| | $CH_4$ | Calibration gas not detected | Possible trace |
| B<br>SULFUR COMPOUNDS | $H_2S$ | Calibration gas not detected | Not found |
| | $SO_2$ | 0.00212 cm/ppm**** | 2,170 ppm |
| | COS | | Not found |
| | Thiophene | Calibration gas not detected | Not found |
| | Methyl-Mercaptan | | Not found |
| | Ethyl-Mercaptan | | Not found |
| C<br>NITROGEN COMPOUNDS | HCN | Equipment problem prevented this analysis | - |
| | NCCN | | |
| | $NH_3$ | | |
| D<br>LIGHT HYDRO-CARBONS | $nC_1$ | 1020/ppm | <10 ppm* |
| | $nC_2$ | 1980/ppm | <10 ppm* |
| | $nC_3$ | 2804/ppm | <10 ppm* |
| | $nC_4$ | 4443/ppm | 28 ppm |
| | $nC_5$ | 7576/ppm | 7 ppm |
| | $nC_6$ | Calibration gas not detected | <10 ppm* |
| | $nC_7$ | Calibration gas not detected | <10 ppm* |
| E<br>HEAVY HYDRO-CARBONS | $nC_1$ | 802/ppm (1122 area units/ng) | 0.78 mg/$m^3$ (1.1 ppm)? |
| | $nC_2$ | 2521/ppm (1882 area units/ng) | <25 ppm* |
| | $nC_3$ | 3083/ppm (1570 area units/ng) | |
| | $nC_4$ | 4103/ppm (1584 area units/ng) | |
| | $nC_5$ | 4859/ppm (1512 area units/ng) | |
| | $nC_6$ | 5028/ppm (1310 area units/ng) | |
| | $nC_7$ | 7462/ppm (1672 area units/ng) | |
| | Other Hydrocarbons | 1522 area units/ng (assumed) | 0.72-5.57 mg/$m^3$*** |

*Not found (below detection limit).

**For a 1.0 cc injection (sample size was always 1.0 cc).

***This includes 5 unidentified peaks as explained in Appendix E.

****Peak height method (for attenuation = 2).

? Peak has not been positively identified.

## B. Flue Gas Entering and Leaving Precipitator

### 1. Total Particulate Matter

EPA Method 17 sampling and analysis for total particulate loading at both the inlet and outlet of the ESP was performed by Entropy Environmentalists, Inc. under contract to ER&E. Pertinent sections of their report may be found in Appendix F, which is summarized below and in Table C-IV-3. These show a collection efficiency of more than 98% for the electrostatic precipitator. Particulate matter was sampled no farther downstream than the precipitator outlet. (Farther downstream is a scrubber which also removes particulate matter.)

It is interesting to note that the coal analysis (Appendix B) indicates that the fuel is 14 wt% ash. Therefore, the 350,000 pounds of coal fired per hour during this test would be expected to produce 50,400 pounds of ash per hour. However, Table C-IV-3 indicates that only 27,100 to 34,300 pounds of fly ash per hour are leaving the boiler in the flue gas stream entering the ESP. Therefore the remainder must be slag, bottom-ash, or economizer ash.

For calculations used in the particulate tests, gas composition was found by Orsat Analysis while heat input and excess air were calculated from "F" factors and related formulas.

### 2. SASS

The Source Assessment Sampling System (SASS) was used by ER&E only at the inlet to the precipitator and included a gas sample as well as entrained particulate matter. Simultaneously, Acurex performed a similar test at the precipitator outlet. The results of the inlet (ER&E) test are reported here while selected results from the outlet (Acurex) test are included in Appendix I.

Sampling occurred on September 10, 1980 from 16:18 to 22:02 when the test was cut short due to a forced change in the plant's operating conditions. On the two days following the test, the sampling system was washed and the samples were made ready to be shipped to ER&E's laboratories for analysis. Plans were also made to ship any excess particulate samples from ER&E to other laboratories for biological analysis.

To summarize the SASS results (details in Appendixes H and I):

- o Low levels of organics were detected (most appear to be alkyl esters).
- o Metals found by Inductively Coupled Plasma Emission Spectroscopy (ICPES) were also found by X-ray energy dispursive analysis in the microscopy studies.

## TABLE C-IV-3

## ELECTROSTATIC PRECIPITATOR (ESP) TESTS

## SUMMARY OF METHOD 17 RESULTS

| Test Number* | ESP Inlet 1 | ESP Outlet 4 | ESP Inlet 2 | ESP Outlet 5 |
|---|---|---|---|---|
| Grains/DSCF | 3.10 | 0.0554 | 4.03 | 0.0667 |
| Pounds/Hour | 27100 | 520 | 34300 | 646 |
| Pounds/MBtu | 5.95[a] | 0.11 | 7.27[a] | 0.14 |
| Collection Efficiency | 98.2% | | 98.3% | |
| Stack Flow (DSCF/Min) | 1018000 | 1096000 | 993000 | 1130000 |
| Excess Air[b] | 46 | | 45 | |
| Heat Input (MBtu/Hr)[c] | 4550 | | 4724 | |
| Moisture (vol. %) | 5.3 | 5.1 | 5.6 | 4.3 |
| CO (vol %) Dry | 0.0 | | 0.0 | |
| $CO_2$ (vol %) Dry | 12.5 | | 12.6 | |
| $O_2$ (vol %) Dry | 6.7 | | 6.6 | |
| $N_2$ (vol %) Dry | 80.8 | | 80.8 | |

[a] Two methods were used to measure particulate loading at the ESP inlet. The data reported here are the result of Method 17 tests which involve a traverse of the duct. These data are considered to be more reliable than the SASS data (Appendix H, Table GH-3) which result from sampling at only a single point.

[b] The excess air calculation uses flue gas composition data obtained from EPA Method 3 performed at the precipitator outlet.

[c] The heat input calculation is based on measurements made at the ESP outlet.

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*Because of a forced load change, planned tests 3 and 6 were not performed.

- Toxic metal concentrations were near or below detection limits.

Inductively coupled plasma emission spectroscopy (ICPES) was used to analyze the XAD-2 resin and the impinger solutions as well as the particulate samples of the SASS train for metals, while cold vapor atomic absorption (AA) was used for mercury. Metal data is summarized in Table C-IV-4. (Details may be found in Appendix H.) Special attention was given to the metals on EPA's list of 13 priority pollutants for wastewater (top of Table C-IV-4).

Most metals (largest amount by mass) were present in the particles, but less than 5% of the total metal was found in the 1 μm cyclone*. However, the metals appeared to be more concentrated on these small particles than on the larger (3 and 10 μm) ones*, probably due to unburned hydrocarbons on the larger fly ash particles. Mercury concentrations, as expected, were higher in the impingers (which are designed to catch volatile elements such as As, Hg, and Sb). Except for mercury, other volatile metals were not found in significant amounts. (It was not considered unusual to find high levels of Fe, Ni, Mn, Mo, and Cr which may have been leached from the stainless steel components of the sampling system.)

Most of the particulate matter consisted of large size particles. 77% of the particulate mass was greater than 10 μm* in equivalent aerodynamic diameter and total particulate loading was 4.23 kg/MBtu (only slightly different from the more reliable Method 17 result already discussed). In this report, method 17 data is used for total particulate loading while SASS is used for particulate size distribution and for analysis of organics and trace metals.

Electron microscopy revealed that the SASS cyclones were efficient at separating the fly ash into size fractions* and that the dominant shape was spherical. (Fly ash samples collected in the ESP hoppers had a rougher surface than those captured by the SASS train at the ESP inlet.) The composition of the particulate was mostly silicates (which probably originated from clays).

X-ray analysis of the fly ash typically showed silicon, lithium, aluminum, potassium, and iron with smaller amounts of calcium, sulfur, and titanium. (Sulfur was the most abundant element detected by X-rays in the coal samples.) About 10% of the particulate SASS sample contained particles rich in iron, sulfur, and titanium. These elements, detected by X-ray energy dispersive analysis were also detected by ICPES.

Organic analysis included chromatographic separation (7 cuts) and compound characterization. Of the SASS samples, the complete organic analysis was performed only on the XAD-2, since there were not enough extractable organics in the other components of

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*For additional comments on particle size distribution, see Appendix H: "Validity of Cyclone Cutpoints".

## TABLE C-IV-4

## METAL DATA ON EMISSIONS FROM CONESVILLE TEST
## (RESULTS REPORTED IN $\mu$ g/g)

| Element | 10 and 3 $\mu$ m Cyclones | 1 $\mu$ m Cyclones | Coal | Fly Ash From Precipitator Hopper | Sluice Water |
|---|---|---|---|---|---|
| Ag | <1.8 | <4.3 | <4.3 | (5.6)$^{b}$ | <0.0025 |
| As | 83$^{b}$ | 960 | (23)$^{a}$ | 220$^{a}$ | <0.0103 |
| Be | <0.43 | 4.1$^{b}$ | 12$^{b}$ | <1.1 | <0.0006 |
| Cd | 11$^{b}$ | 26$^{a}$ | <7.9 | 33$^{b}$ | <0.0047 |
| Cr | 62 | 290 | <1.3 | 92 | <0.0007 |
| Cu | 69 | 200 | 20 | 120 | <0.0002 |
| Hg | 0.0018 | 0.0088 | 0.081 | 0.014 | <0.0001 |
| Ni | 1.4 | 360 | <11 | 240$^{a}$ | (0.0098) |
| Pb | <7.5 | 180$^{a}$ | <13 | 110$^{b}$ | (0.0084) |
| Sb | <11 | (67)$^{b}$ | <26 | (84)$^{b}$ | (0.023)$^{a}$ |
| Se | 66$^{b}$ | 130$^{b}$ | <26 | (120)$^{b}$ | (0.021)$^{a}$ |
| Tl | 23$^{b}$ | 110$^{b}$ | <8.2 | 55$^{b}$ | <0.0048 |
| Zn | 180 | 1000 | 50 | 330 | 0.109 |
| Al | 64000 | 110000 | 15000 | 98000 | 0.20 |
| Ba | 590 | 1600 | 41 | 940 | 0.051 |
| Ca | 6800 | 1600 | 930 | 15000 | 260 |
| Co | (2.3)$^{b}$ | 38$^{a}$ | 15 | <3.8 | <0.002 |
| Fe | 130000 | 160000 | 44000 | 210000 | 0.27 |
| K | 9300 | 19000 | 1800 | 17000 | 13 |
| Li | 100 | 220 | 31 | 180 | 0.13 |
| Mg | 2900 | 6300 | 440 | 4500 | 67 |
| Mn | 200 | 490 | 26 | 330 | 0.13 |
| Mo | 66$^{b}$ | 260$^{b}$ | (18)$^{b}$ | 130$^{b}$ | (0.006) |
| Na | 1600 | 3400 | 750 | 3200 | 47 |
| P | 360 | 3000 | (85)$^{a}$ | 850 | 0.093$^{a}$ |
| Si | 100000 | 160000 | 18000 | 180000 | 0.21 |
| Sn | <5.7 | 60$^{b}$ | <13 | <15 | <0.0078 |
| Sr | 240 | 500 | 24 | 400 | 0.57 |
| Ti | 3300 | 5900 | 440 | 5100 | 0.029 |
| V | 110$^{a}$ | 380 | (13)$^{a}$ | 170$^{a}$ | <0.0045 |

a Data less reliable due to significant spectral or background interferences.

b Data unreliable due to strong interferences or weak signals.

( ) Means that the value is less than 3 times the ICPES detection limit or the blank value. These results may not be significant since they are more easily affected by background fluctuations.

< Means that the printed value represents the lower limit of detection for the element in that particular sample.

the SASS train. The GC data together with IR and MS analysis indicate that most of this material appears to be esters, but these materials were also found in the blank. Details for each of the 7 cuts as well as a note on the XAD-2 blank are included in Appendix H.

For every million Btu (= $1.05 \times 10^9$ J, or about 83 pounds) of coal burned, the fuel contains about 370,000 mg of total organic material or 350 ng/J. Other samples contained organics as shown in Table C-IV-5.

## TABLE C-IV-5

### SASS TOTAL ORGANICS

| Sample | (ng of organics)/(Joule of fuel burned) | |
|---|---|---|
| Sluice Water | 0.58 mg total organics/liter of water[a] | |
| Coal | 350.[b] | |
| PPTR Ash | <0.0518[c] | |
| SASS Sample | | |
| 1 μm cyclone | <0.0637 | d |
| 10 and 3 μm cyclone | 0.0874 | |
| XAD-2 resin[e] | 0.415 | |
| Organic condensate | 0.00364 | |
| Total (for SASS only) | 0.570 | |

[a] No information is available concerning the amount of sluice water that flows per million Btu (or per Joule) of fuel burned.

[b] (9.77 mg/g--from Appendix H, Table GH-10) (454 g/pound) (83 pounds/MBtu) ($9.48 \times 10^{-10}$ MBtu/J) = 0.00035 mg/J.

[c] (<0.01 mg/g) (454 g/pound) (83 pounds coal/MBtu) ($9.48 \times 10^{-10}$ MBtu/J) (0.145 pounds ash/pound coal — from Appendix B) = $<5.18 \times 10^{-8}$ mg/J

[d] Obtained after multiplying (mg)/(this test) from Table GH-10 in Appendix H by $1.82 \times 10^{-8}$. ($1/1.82 \times 10^{-8}$ is the number of Joules of fuel that had to be burned to produce the amount of flue gas sampled during this test. [See Example 2 in Appendix D.])

[e] The background level of organics in the XAD-2 blank (Appendix H, Table GH-10) was about half of the total value measured. Therefore, the organics reported here may have a wide error bar.

### SASS Wash Down (Field Error Analysis)

Generally, the ER&E SASS sampling and analysis was performed according to plan. However, some procedures did not occur as planned, and may have introduced some degree of error into the SASS results. These items are presented below.

- The probe was not tightly sealed in the duct.

  The pitot tube reading was observed to change each time the packing around the probe was adjusted. Also, following the test, a greasy substance (possibly condensed organic matter) was observed on parts of the outside of the probe. These two observations indicate that some cool ambient air may have been drawn into the duct (which was under a slight vacuum) through the sampling part, and may have flowed past the nozzle and pitot tube.

- Organic condensate was not drained during sampling.

  Calculations show that a certain amount of the organic condensate may have overflowed into the first impinger. The analytical chemist was informed of the amount and has taken this into consideration during the analytical calculations.

- Silica gel was not changed during sampling.

  The silica gel in the fourth impinger may have become saturated during the test. If so, then the SASS method may not be as reliable as Method 17 for determination of flue gas moisture content. As a result of this uncertainty, the Method 17 results (rather than SASS) are used for flue gas moisture conteut in this report.

- Part of Impinger No. 3 was mixed with Impinger No. 1 after sampling.

  The No. 1 impinger catch as shipped to the laboratory contained part of the catch from impinger No. 3, as well as part of the organic condensate. The analytical chemist was informed of the quantities involved and has considered this during the analysis.

- Heavy dust loading caused frequent filter plugging.

  Because of the high dust loading at the sampling point (ESP inlet), the final filter would begin to plug soon (within minutes) after each fresh filter was installed. Initially, it was thought that this caused the sampling rate to be somewhat slower than isokinetic. However, subsequent post-test calculations indicated that the sampling rate was 101.9% isokinetic.

## C. Coal, Fly Ash (from precipitator hopper), and Sluice Water

Samples of coal, fly ash (from precipitator hopper), and sluice water, were shipped to various laboratories for analysis. Sluice water (sampled at the discharge to the settling pond, 0.5 miles distant from the boiler) was measured in the field for pH and temperature.

The sluice water sampling point was not probed with a thermometer. However, a qualitative estimate placed its temperature at about 32-38°C. On the day following the test (when the sample temperature was 27°C) its pH was 6.9 to 7.1.

As indicated in Table C-IV-6, coal, fly ash, and sluice water were each analyzed physically, chemically, and biologically by several specialized laboratories reporting separately. The reports are summarized in Appendixes H, I, and J. Key findings are summarized below.

## TABLE C-IV-6

## SAMPLE ANALYSIS DONE BY SPECIALIZED OUTSIDE LABORATORIES ON COAL, PRECIPITATOR HOPPER ASH, AND SLUICE WATER

| Sample / Type of Analysis | Coal | Fly Ash (from precipitator hopper) | Sluice Water |
|---|---|---|---|
| Physical Analysis:<br>o Heat Content<br>o Ash Fusion Temp.<br>o Ash Elements | ← Exxon, Baytown (ER&E) → | | Not Done |
| Chemical Analysis | ← Exxon, Linden (ER&E) → | | |
| Bio-Assay using aquatic life forms | ← Battelle, Columbus Laboratories (BCL) → | | |
| Bio-Assay using land animals | ← Research Triangle Institute (RTI) → | | |

### 1. Chemical and Physical Analysis

Particulate matter sampled during this test was examined by microscope and revealed that the shape of the ESP fly ash (sampled from the ESP hoppers) had a greater departure from sphericity than did the particulate catch from the ESP inlet (from the SASS train). The ESP ash particles ranged in size from 1 to 40 µm, and contained mostly silicates.

Sluice water effluent samples contained very low levels of metal anions. The Acurex data shows that as the water passes through the system, there is an increase in acidity, total suspended solids, chemical and biological oxygen demand, and total organic carbon.

The coal extract was separated into 7 fractions, but the spectra of each fraction was generally too complex to be analyzed by EPA Level 1 procedures. Instead, a list of the major peaks may be found in Appendix H and shows that the extract was highly aromatic, highly oxygenated material containing phenolics, carboxylic acids, amides, and aliphatics. Most aromatic rings had two or more substituents and mono-substituted aromatics were rare.

### 2. Biological Analysis

The ER&E results indicate that the coal, electrostatic precipitator (ESP) ash and sluice water are not mutagenic. The Rat Alveolar Macrophage (RAM) Assays were also negative, however the Chinese Hamster Ovary (CHO) Cell Assay yielded toxic responses with coal leachates and with sluice water. (The ESP ash was not subjected to this assay.) While moderate to high toxicity was also recorded for some of the aquatic assays, the sluice water caused no toxicity to any of the aquatic species studies, but was stimulatory to the growth of algae. The bio-assay data for this boiler is summarized in Table C-IV-7. (For the reader's convenience, some of the supplemental Acurex data is also summarized therein.)

## D. Plume Opacity

Observations made by an EPA-certified* "smoke-reader" indicated that plume opacity was 30% to 40% during the Level 1 test. Typically, at this boiler, the observers opacity readings have been much lower than those of the plant's transmissometer. An unusual malfunction in the plant's data logging computer caused the transmissometer data to be unavailable during this test.

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*In order to be certified, the observer must "read," consecutively, 25 samples of black smoke, and 25 of white smoke from (randomly) 0 to 100% opacity. No reading may be in error by more than 15 percentage points, and the average error in both the black & white categories must each be less than 7 1/2 percentage points as compared to a calibrated in-stack transmissometer.

## TABLE C-IV-7

## BIO-ASSAY RESULTS (SUMMARY)

| | Bottom Ash/Water Slurry (C in Fig. C-III-1) | | Precipitator (ESP) Hopper Ash (F in Fig. C-III-1) | | Coal (B in Fig. C-III-1) | | ESP Outlet To Stack (XAD-2) (E in Fig. C-III-1) | |
|---|---|---|---|---|---|---|---|---|
| | Exxon Data | Acurex Data | Exxon Data | Acurex Data | Exxon Data | Acurex Data | Exxon Data | Acurex Data |
| Ames Mutagenicity (Salmonella/Microsomal Mutagenesis Assay) | U | U | U | U | U* | – | – | L |
| Rat Alveolar (Lung) Macrophage Cytotoxicity Assay (RAM) | – | U | U | U | U | – | – | – |
| Rodent Cell Clonal Toxicity Assay (Chinese Hamster Ovary - "CHO") | L | L | – | – | M | – | – | L |
| In Vivo Oral Rodent (Whole Animal Acute Toxicity - Rat) | U | – | U | U | U | – | – | – |
| Fresh-Water Fish (Fathead Minnow) | U | U** | U | U** | M | – | – | – |
| Fresh-Water Daphnia Magna (Water Flea) | U | U** | M | U** | H | – | – | – |
| Fresh Water Algae | U | | H | | H | – | – | – |
| $EC_{50}$*** (Dose that kills 50%) | | 2.5 to 6.7 mg/L | | 328 to 367 mg/L | | | | |
| $EC_{95}$*** (Dose that kills 95%) | | 4.4 to 16.2 mg/L | | 830 to 963 mg/L | | | | |

NOTES

* Was not mutagenic, but was toxic to cells. (No mutations had been observed up to the time of cell death.)

** Dose = 1000 mg of sample/liter of culture.

*** Bottom ash affected acidity in Acurex's algae test.

| | |
|---|---|
| 0 ash | pH = 7.1 |
| 25 mg/L | pH = 3.6 |

KEY

H = High toxicity
M = Moderate toxicity
L = Low toxicity
U = Undetected
– = Not tested (usually due to insufficient sample)

## V. DISCUSSION OF LEVEL 1 RESULTS

For the SASS tests done on the inlet and outlet of the precipitator, both the inlet and the outlet samples showed a size distribution favoring large particles. However, for the outlet sample, the ratio of large to small particles is not as great as for the inlet sample, thus indicating that the precipitator, as expected, is more efficient at removing large particles than small ones.

The SASS train (used to sample the precipitator inlet) captures organics in various components or stages of the sampling train. Most of these organics were found in the stage known as the "organic module," and more specifically were on that stage's XAD-2 resin, which is designed to collect organics from the vapor phase. The next largest amount of organic matter was found on the larger particles trapped in the 10 and 3 μm cyclones. A still smaller amount was found on the particles in the 1 μm size range. However, this may have been due to the fact that the total mass of the large particles was so much greater than the small ones. (77% of the fly ash particle mass was of the 10 μm size range.)

Actually, the amount of organics per particle mass was less for the large particles (22 μg* of organics per gram of 10 and 3 μm particles) than for the small ones (<700 μg** of organics per gram of 1 μm particles). This supports the belief that the process by which organics become part of the particles, is condensation. And, since condensation is a surface effect, it favors smaller particles because of their higher surface area to mass ratio. (The amount of condensed materials reported herein may not reflect what actually happens at ambient conditions, since it is expected that as the effluent gas cools to below the sampling temperature (after leaving the stack) more material may condense.)

In addition to organics, trace metals were also analyzed. For the precipitator inlet sample, the metals seemed to favor the small particles, but the amounts of EPA-designated toxic metals were near or below detection limits.

---

$$^{*}\left(\frac{(4.8\text{ mg of organics in the 10 and }3\,\mu\text{m cyclones})}{\left(\begin{array}{c}(169\text{ g of particles of the }10\,\mu\text{m size})\ +\\ (45\text{ g of particles of the }3\,\mu\text{m size})\end{array}\right)}\right) = 22\ \frac{\mu g}{g}$$

This shows that the larger (10 and 3 μm) particles are 0.0022% organics.

$$^{**}\ \frac{(<3.5\text{ mg of organics on the }1\,\mu\text{m particles})}{(5.026\text{ grams of }1\,\mu\text{m particles})} = <700\ \mu g/g$$

The "<" sign is representative of an uncertain upper limit.

The EPA's Industrial Environmental Research Laboratory/RTP, in 1977, developed an approach to assist in performing cost effective characterizations of control technology and source discharge emissions. This approach involves the concept of trigger values, and Discharge Multimedia Environmental Goals (DMEGs). When applied to preliminary characterization data this approach can be used to rank individual chemicals and discharge streams in terms of their relative potential for environmental impact and thus suggest which species and streams warrant further analysis. The trigger values (DMEGs) were calculated using simplified models based upon health and ecological information available at that time. Thus, it should be made clear that the DMEGs are not applicable to risk assessment. They are only an engineering tool aimed at suggesting, in an organized fashion, which waste streams and potential pollutants warrant further investigation.

Table C-V-1 lists the gas-phase source emissions for thirteen of the elements analyzed in this study and compares their respective concentrations with the 1977 DMEG values (formerly called MATE - Minimum Acute Toxicity Effluent - values). Of the reliable data, only copper, chromium, nickel and zinc have gaseous media source emission rates in excess of their DMEG values. But, the chromium and nickel detected probably came from the stainless steel components of the sampling system. Similarly, copper and zinc are commonly found in piping and galvanized metal coatings around a power plant. Thus, these metals may not represent products of combustion, and as such, should not necessarily be a cause of concern. Other metals, because of their high concentration in the particulate phase, may have originated in the coal. The coal, however, was not analyzed for these metals.

DMEG values for other pollutants may be found in references 2 through 6 for comparison with emission rates reported herein. Similarly, reference 7 presents information on typical emissions.

## TABLE C-V-1

## EMISSIONS OF 13 EPA PRIORITY (FOR WASTEWATER) POLLUTANT METALS

(COMPARISON WITH LIMITING DMEG VALUES FOR GASEOUS SOURCES)

| Element | Source Emission Rate (Gaseous Media Only) |  | Discharge Stream Multimedia Environmental Goals (DMEGs) For Source Emissions in Gaseous Media. |  |
|---|---|---|---|---|
|  | mg/MBtu* | $\mu g/m^3$** | Based on Health Effects ($\mu g/m^3$) | Based on Ecological Effects ($\mu g/m^3$) |
| Ag | <8.4 | <30 | 10 |  |
| As | 500[b] | 1800[b] | 2 |  |
| Be | <2.7 | <10 | 2 |  |
| Cd | 48[b] | 170[b] | 10 |  |
| Cr | 1400 | 5040 | 1 |  |
| Cu | 1100 | 3960 | 200 |  |
| Hg | 3.3 | 12 | 50 | 10 |
| Ni | 1400 | 5040 | 15 |  |
| Pb | (31)[a] | (112)[a] | 150 |  |
| Sb | <56 | <200 | 500 |  |
| Se | 290[b] | 1040[b] | 200 |  |
| Tl | 110[b] | 40[b] | 100 |  |
| Zn | 1800 | 6480 | 4000 |  |

a Data less reliable due to significant spectral or background interferences.

b Data unreliable due to strong interferences or weak signals.

( ) Means that the value is less than 3 times the ICPES detection limit or the blank value. These results may not be significant since they are more easily affected by background fluctuations.

< Means that the printed value represents the lower limit of detection for the element in that particular sample.

* From Appendix H, Table GH-5.

** Assumes 9820 $ft^3$ (278 $m^3$) of flue gas per MBtu. These values are "worst-case" emissions since 9820 $ft^3$/MBtu (278 $m^3$/MBtu) is the value for undiluted dry flue gas.

## VI. REFERENCES (FOR PART C: Level 1 Test)

1. IERL-RTP Procedures Manual: Level 1 Environmental Assessment (second edition). EPA - 600/7-78-201, October, 1978, pgs. 55 and 56.

2. Multimedia Environmental Goals (MEG's) for Environmental Assessment. Volume I.

   Prepared by J. G. Cleland and G. L. Kingsbury of Research Triangle Institute for the U.S. Environmental Protection Agency.

   EPA No. EPA-600/7-77-136a. NTIS No. PB 276 919. Nov., 1977.

3. Multimedia Environmental Goals for Environmental Assessment; Volume I (Supplement A).

   Prepared by J. G. Cleland, G. L. Kingsbury, and J. S. Watson of Research Triangle Institute for the U.S. Environmental Protection Agency.

   EPA No. EPA-600/7-80-041. March, 1980.

4. Multimedia Environmental Goals for Environmental Assessment; Volume II - MEG Charts and Background Information.

   Prepared by J. G. Cleland and G. L. Kingsbury of Research Triangle Institute for the U.S. Environmental Protection Agency.

   EPA No. EPA-600/7-77-136b. NTIS No. PB 276 920. Nov., 1977.

5. Multimedia Environmental Goals for Environmental Assessment; Volume III. MEG Charts and background information summaries (Categories 1-12).

   Prepared by G. L. Kingsbury R. C. Sims, and J. B. White of Research Triangle Institute for the U.S. Environmental Protection Agency.

   EPA No. EPA-600/7-77-176a. August, 1979.

6. Multimedia Environmental Goals for Environmental Assessment; Volume IV. MEG Charts and background information summaries (Categories 13-26).

   Prepared by G. L. Kingsbury R. C. Sims, and J. B. White of Research Triangle Institute for the U.S. Environmental Protection Agency.

   EPA No. EPA-600/7-77-176b. August, 1979.

7. Compilation of Air Pollutant Emission Factors — Third Edition, Including Supplements 1-7. U.S. Environmental Protection Agency, Office of Air and Waste Management, Office of Air Quality Planning and Standards. Research Triangle Park, N.C. August 1977. EPA No. AP-42. NTIS No. PB-275525.

# PART D

# CORROSION PROBE TESTS

## I. BACKGROUND

The Conesville No. 5 boiler was designed to meet the New Source Performance Standard (NSPS) for $NO_x$ emissions applicable at the time of construction (0.7 lb/MBtu, or 301 ng/J). Under this program, the effect of such "Low $NO_x$" operation on water wall corrosion rate was evaluated.

### A. Purpose for Corrosion Testing

One method of decreasing $NO_x$ emissions for compliance with NSPS regulations, is to decrease the amount of excess air in the burner zone. However, an oxygen deficient flame can be corrosive, especially in the presence of high sulfur concentrations. From a corrosion point of view, a furnace wall coated with high-sulfur slag while exposed to a chemically reducing (oxygen deficient) atmosphere is an undesirable situation which could lead to increased corrosion.

### B. Previous Corrosion Probe Testing by ER&E

Corrosion testing by use of corrosion probes is a relatively new art. The present program uses probes of third generation design. In the first generation corrosion probes used by ER&E, each probe consisted of a flat square plate a few inches on a side and about 1/8 inch thick mounted on a probe holder a few feet long which supplied cooling air to the back of the plate. The assembly was inserted into the furnace through an inspection door and the front of the plate was exposed to the furnace gases. This probe design was notorious for allowing the supply of cooling air to leak into the furnace thus sheathing the plate in a capsule of clean air and preventing it from being exposed to the potentially corrosive furnace gases. Furthermore, the cooling effect of the air was not uniform and caused large temperature gradients over the small plate. This corrosion probe design was quickly abandoned in favor of the second generation of corrosion probes.

In the second generation of corrosion probes the corrosion coupons (of which three of various materials were typically mounted on each probe), were fabricated from actual boiler wall tube materials. The assembly of 3 cylindrical coupons, screwed end to end, formed a cylinder about 6 inches long and 1-1/2 inches in diameter. It was inserted horizontally a few inches into the boiler through an inspection door and was cooled by air circulating inside the cylindrical assembly.

The first use of these second generation probes involved high temperature accelerated corrosion testing of "acid-pickled" coupons. But correlation between probe corrosion rates and actual wall corrosion rates was poor, so the practice of pickling was stopped. High temperature testing was also stopped, and in subsequent tests, the coupons were cooled to the same temperature as the boiler walls.

Corrosion rates were determined by weight loss analysis after slag was removed in an ultrasonic bath containing microscopic glass beads. ("Control" specimens were also included in the bath.) However, some investigators felt that the horizontal orientation of the probes caused unnatural slag formations on the probes leading to extraordinary corrosion, therefore, the third generation of probe coupons (designed by Combustion Engineering, Inc.) were mounted vertically in the boiler and more than ever before, simulated a piece of boiler wall-tube. This was the probe design used for the tests described in this report.

### C. Other Methods for Determining Corrosion Rate

Corrosion testing by probes was only one of three methods used to determine boiler wall corrosion rates under this program. The three methods were:

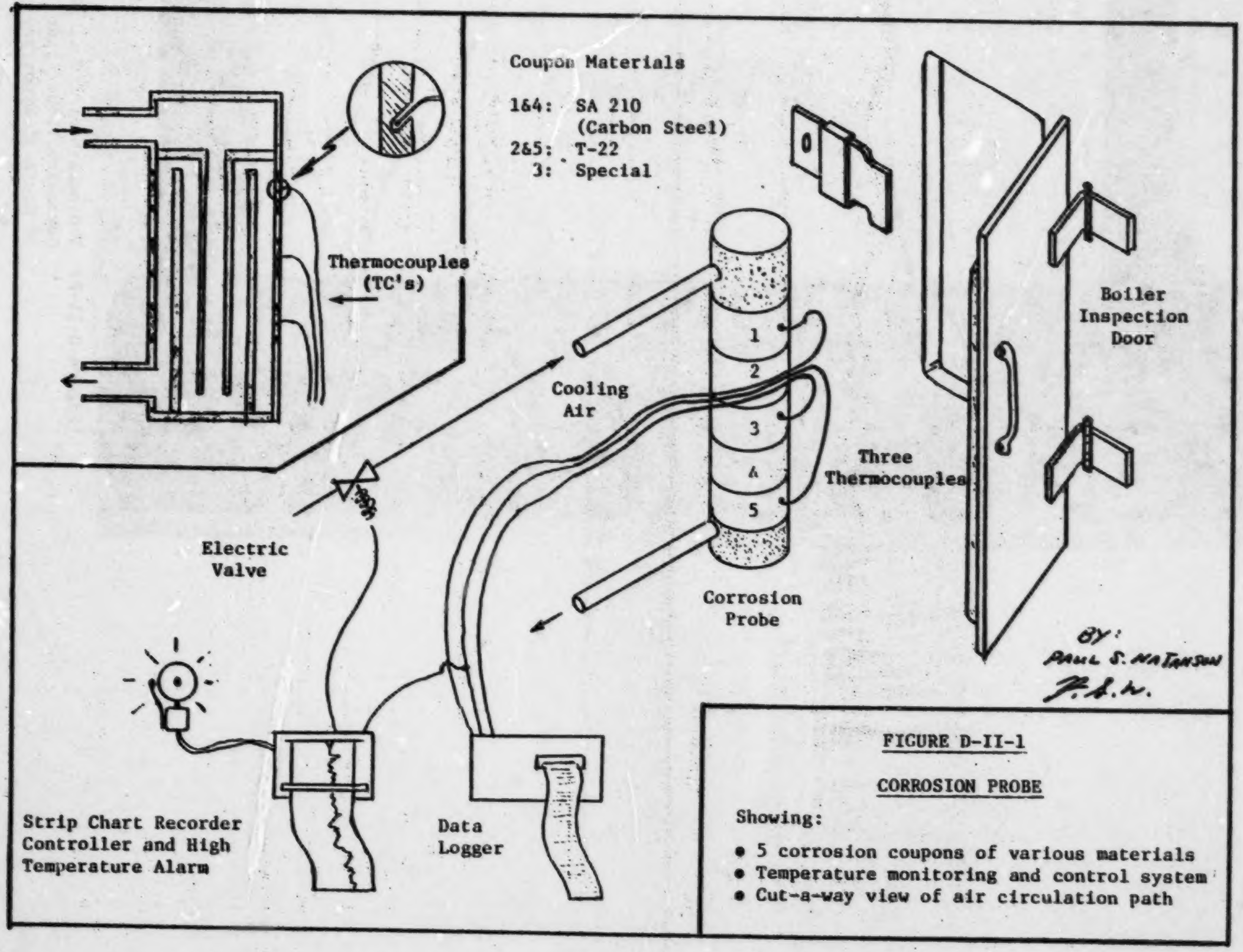
- Ultrasonic Thickness (UT) Mapping (of the furnace walls)
- Corrosion Panels (specially prepared, pre-characterized sections of wall tube; installed in the furnace wall circuit for analysis)
- Corrosion Probes (pieces of boiler wall tube inserted into the furnace through inspection doors with corrosion rate determined by weight loss analysis)

In addition, furnace gas was sampled from 40 locations along the walls of the furnace to identify locally corrosive environments for correlation with actual corrosion measurements.

## II. EXPERIMENTAL PROCEDURES

### A. Probe Design

The corrosion probes (shown in Figure D-II-1) and control systems were designed and built by Combustion Engineering (CE), Incorporated. The geometry was such that each probe could be inserted into the furnace through a standard 4" X 10" CE inspection door. Each probe contained 5 corrosion coupons (also called "test rings") of various materials including one surface coated test ring of either Metco coating 444 or Hastelloy C-276. These are special corrosion resistant alloys. Three thermocouples were provided for temperature measurement and control. The probes were air cooled to keep the center coupon at 650°F.



BY:
PAUL S. NATANSON
P.S.N.

FIGURE D-II-1

CORROSION PROBE

Showing:

- 5 corrosion coupons of various materials
- Temperature monitoring and control system
- Cut-a-way view of air circulation path

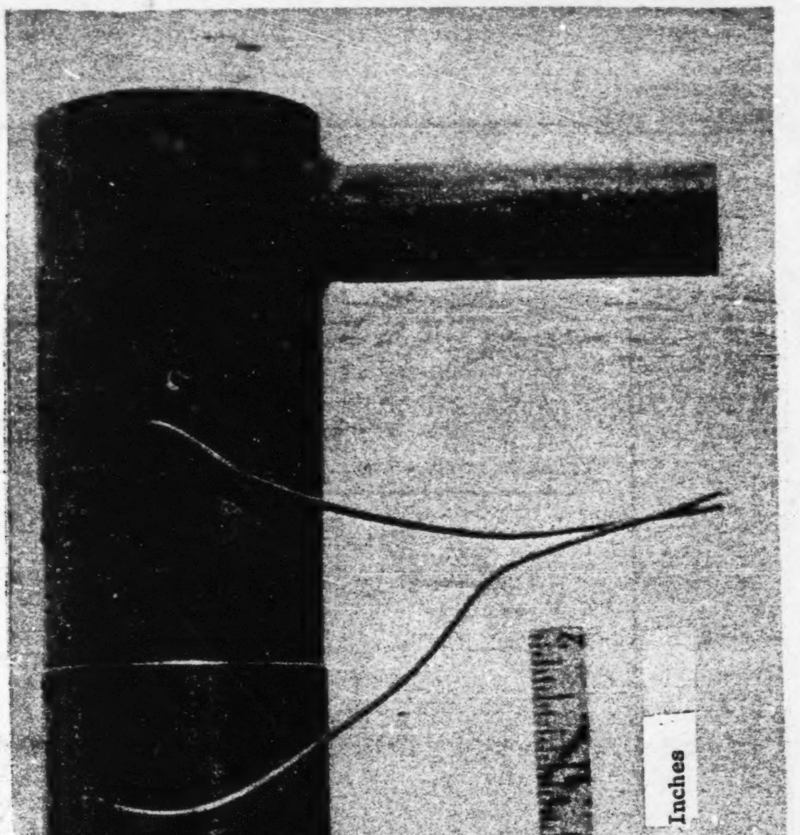


Figure D-II-2: Photograph of a Typical Corrosion Probe After 30 Hours of Exposure.

For each of the five probes, a continuous log of the middle coupon temperature was kept on a strip-chart recorder-controller which was also used to control the cooling air and high temperature alarm systems. A data logger recorded all three thermocouple outputs from each of the 5 probes at least once per hour.

Three tests using corrosion probes were performed. Each test involved exposing 5 probes (each containing 5 coupons) to the furnace gases for a known time period. For the first test, the exposure period was 30 hours. The second used a 300 hour exposure, and the third lasted 1000 hours. During the tests, the boiler was operated normally, and a log was kept of boiler load.

## B. Probe Locations

Each of the five corrosion probes was inserted into the boiler through one of eight standard size inspection doors specially installed for the test. Each of the eight doors was part of a "corrosion panel" (another device for measuring corrosion) and, for identification, each corrosion probe was assigned the same "ID" number as its corresponding corrosion panel. Figure B-II-4 and Table D-II-1 specify the probe locations and identification.

## C. Analytical Procedure

Coupon corrosion rate was determined by weight loss analysis as well as by micrometer measurement of coupon wall thickness after carefully removing slag deposits by scrubbing and brushing with a mild acid solution. These analyses were performed by CE, Inc.

For each coupon, to convert the weight loss data to a thickness change, first the weight loss (grams) for each coupon was divided by the exposed surface area* of the coupon ($cm^2$) to give the weight loss per exposed surface area ($g/cm^2$). This number was then divided by the density of the coupon material ($7.83\ g/cm^3$) to give the average thickness change (in centimeters) for the exposed surface and was then converted to units of inches or mils. Dividing this number by the exposure time gives the average corrosion rate for the period (inches or mils** per year).

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*For each coupon, half of its outside surface is exposed to the radiant heat and slag in the furnace. The other half sees the furnace wall. Hence for each coupon, the exposed area is equal to half of the total visible outside surface area.

**One mil = 0.001 inch.

## TABLE D-II-1

## CORROSION PROBE IDENTIFICATION

| PROBE ID NUMBER | LOCATION OF PROBE DURING EXPOSURE PERIOD (ELEVATOR FLOOR NUMBER) | FIRST TEST (30 HOUR EXPOSURE) | SECOND TEST (300 HOUR EXPOSURE) | THIRD TEST (1000 HOUR EXPOSURE) |
|---|---|---|---|---|
| (SEE FIGURE B-II-4) | | COUPON ID No's. (TOP TO BOTTOM, CONSECUTIVE) | | |
| 1 | 9th Floor Front | A1 to A5 | D1 to D5 | E5 to E1 |
| 2 | 7th Floor Front | A6 to A10 | D6 to D10 | E10 to E6 |
| 4 | 5th Floor Front | A16 to A20 | D11 to D15 | E15 to E11 |
| 5 | 7th Floor Rear | A11 to A15 | D16 to D20 | E20 to E16 |
| 6 | 6th Floor Rear | A21 to A25 | D21 to D25 | E25 to E21 |

## III. RESULTS AND DISCUSSION OF CORROSION PROBE TESTS

Experience (EPA Contract 68-02-1415) indicates that in short term probe tests, corrosion occurs at an accelerated rate. Therefore, the probe data should be used for qualitive comparisons only, and should not be considered to represent true wall corrosion rates. The panel and wall measurements discussed in Part E of this report are believed to more accurately reflect the true wall corrosion rates.

The data generated by the corrosion probes used in this program indicate that:

- The longer the exposure time, the closer was the corrosion rate to that expected of, and actually measured on, real wall tubes.
- For these tests conducted on Conesville No. 5 (a boiler using over-fire air), losses for both carbon steel tubing (SA-210) and T-22 tubing were similar to losses for units without overfire air.
- Metallurgical evaluation of the test rings revealed no deleterious effects due to exposure in this test program.

Probe locations, exposure times and coupon identifications are shown in Figure B-II-4 and Table D-II-1. Note, for example, that during the 30-hour test, probe No. 1 contained test rings A-1 through A-5 and was exposed on the front wall at the highest elevation. (Test ring No. A-4 was submitted for metallurgical examination and is discussed below.)

Metallurgical examinations were performed on test rings A-4 from the 30 hour test, and D-3 and D-4 from the 300 hour test. (Rings from the 1,000 hour test, sent out for metallurgical examination, were lost in shipment.) From visual inspection, it was apparent that probes 5 and 6 (coupons D16-D20 and D21-D25, respectively) from the 300 hour test had overheated during their period of exposure. Hence, they are not used in the analysis presented in this report.

Physical measurements (by micrometer) taken before and after exposure of each test ring revealed minimal wall losses. The average maximum wall loss was about 2 mils. Occasionally, greater losses were observed on coated specimens where the coating had spalled or been removed. Two overheated probes showed "accelerated" wastage; i.e., approximately one-half of the wall thicknes was lost. These atypical results were dismissed as "outliers" in the analysis of the data.

The data generated by the probes at 30 hours, 300 hours and 1,000 hours fall on the exponential upward portion of a typical corrosion curve, but other data (discussed elsewhere in this report) indicate that tube metal wastage under these low $NO_x$ conditions levels off after 1,000 hours. The 1000 hour test shows a wastage rate similar to the wastage rate for actual wall tubes as exemplified by the test-panel measurements (discussed in part E of this report) after about 12,000 hours of exposure.

Weight loss data acquired for the individual test rings showed slight differences for the 30-hour test and the 300-hour tests. The samples exposed for 1,000 hours revealed a significant increase in weight loss which was not strongly reflected by the micrometer measurements as can be seen on Table D-III-1. That table also shows that, as expected, the shortest exposure time has the highest corrosion rate. The corrosion rate slows down after new metal has been exposed and conditioned for a time.

The use of the mechanically bonded coatings used on some of the specimens in this test, were not advantageous as compared to unprotected test rings.

The deposit (slag buildup) on the coupons used for the 1,000-hour test (the "E" series) was more than the deposit from the 30 and 300 hour tests, and was of sufficient amount to be removed for analysis. A deposit sample was removed from test rings E3, E9, E13, E17, and E23 for analysis.

Chemical analyses of deposits removed from these probes (exposed for 1,000 hours at Conesville) are typical of external deposits from coal-fired boilers. Insignificant concentrations of corrosion by-products (i.e., sulfur, chromium and nickel) were found (by x-ray flourescence) in all the deposits analyzed. Also, a Perkin-Elmer Model 240 Carbon-Hydrogen-Nitrogen analyzer showed low amounts of carbon in these deposits. High quantities would be indicative of possible reducing conditions existing on the waterwall, which could result in corrosion.

Metallographic evaluation was performed on both coated and non-coated test rings to determine the effectiveness of these materials. Metallurgically, the non-coated test rings were not affected by their exposure during these tests. No pitting or intergranular attack was found. The examined coated samples show the Metco 444 to be thinner due to exposure. The porosity of the coatings may be the dominant factor causing the increased weight losses generated by these coated test rings, and the data from these experimental coatings is not further considered. The following paragrphs were transcribed from CE's report and give details of the metallurgical examination. (Additional details may be found in Appendix L.)

The samples submitted for metallurgical examination (by Combustion Engineering, Inc.) were identified as follows:

| | |
|---|---|
| C-17 | SA213, T-22 bare |
| D-3 | SA210, bare |
| C-4 | SA210, surface coated with C-276 |
| A-4 | SA210 surface coated with Metco 444 |
| D-4 | SA210 surface coated with Metco 444 |

Coupon C-17, T-22 bare

The microstructure of this coupon appeared normal for T-22. The OD surface exhibited some slight irregularities, but evidence of corrosion attack such as pitting and inter-granular penetration, was not apparent in the examined areas.

## TABLE D-III-1

## COMPARISON OF DIRECT METHOD (MICROMETER) AND INDIRECT METHOD (WEIGHT LOSS METHOD) FOR DETERMINING CORROSION RATE

| | | Thickness Loss (Mils) Calculated Values Based on Measured Weight Losses | | Mils/yr | Thickness Loss (Mils) Maximum Actually Measured Values from Micrometer Readings | |
|---|---|---|---|---|---|---|
| Exposure Time | Probe ID | Average for SA-210 Coupons | Average for T-22 Coupons | Avg For All Uncoated Coupons | Average for SA-210 Coupons | Average for T-22 Coupons |
| 30 Hours | Probe 1 | 0.257 | 0.309 | 82 | 1 | 1 |
| | Probe 2 | 0.251 | 0.281 | 78 | 1 | 1 |
| | Probe 4 | 0.101 | 0.144 | 36 | 1 | 1 |
| | Probe 5 | 0.407 | 0.297 | 103 | 1 | 1 |
| | Probe 6 | 0.185 | 0.257 | 65 | 1 | 1 |
| | Avg | 0.240 | 0.258 | 73 | | |
| 300 Hours | Probe 1 | 0.387 | 0.456 | 11 | 1 | 1 |
| | Probe 2 | 0.210 | 0.474 | 11 | 1 | 1 |
| | Probe 4 | 0.313 | 0.488 | 13 | 1 | 1 |
| | Probe 5* | 3.37 | 4.32 | - | 4 | 8 |
| | Probe 6* | 33.0 | 45.9 | - | 66 | 82 |
| | Avg | 0.303 | 0.473 | 12 | | |
| 1000 Hours | Probe 1 | 2.28 | 1.87 | 17 | 2 | 2 |
| | Probe 2 | 3.08 | 2.36 | 23 | 5 | 2 |
| | Probe 4 | 2.04 | 1.26 | 15 | 3 | 1 |
| | Probe 5 | 1.04 | 0.94 | 8 | 1 | 2 |
| | Probe 6 | 5.28 | 4.21 | 31 | 4 | 4 |
| | Avg | 2.74 | 2.13 | 19 | | |

*Over heated, not included in averages.

Coupon D-3, SA210 bare

This medium carbon steel material was exposed as an unprotected bare metal coupon, and also as a base metal for the surface coatings. The bare metal coupon exhibited a smooth appearing OD surface with no evidence of a corrosive attack.

Coupon C-4, C-276/SA210

Hastelloy C-276 is a nickel base coating material that is generally applied to a base metal by flame spray. Inherent in the process are coatings that contain some oxides, voids, and thickness variations. The examined coupon appeared to be typical with no unusual surface conditions. The coating seemed to be intact along the full length of the metallographic specimen leaving no area of the base metal unprotected. Several areas were noted along the coating-base metal interface that appeared to be not fully bonded, but in no instance was the coating pulled away from the base metal.

Coupons A-4 & D-4, Metco 444/SA210

Metco 444 is a nickel base (approx. 74%) coating material that can be applied to a base metal by the flame spray or plasma process. The method of application was not reported for the two submitted coupons, but both exhibited characteristics generally associated with the flame spray product. Examination showed the coating of both samples to contain oxides, voids, and thickness variations in addition to some incomplete bonding along the coating-base metal interface. The coating along the specimen surface, as with the C-276, appeared to be intact, with no detected areas of exposed base metal.

The following summary observations were made concerning the corrosion probe results:

- New metal corrodes at a fast rate, but as time goes on, the corrosion rate slows down and approaches the expected, and actually measured long-term boiler tube corrosion rate.
- The corrosion rate for the SA-210 material was similar to the rate for the T-22 coupons.
- No correlation was found between corrosion rate and location within the furnace.
- All deposits contained large amounts of iron.
- No correlation was found between the amount of sulfur in the deposit and the corrosion rate.

# PART E

# WALL MEASUREMENTS AND CORROSION PANEL TESTS

## I. BACKGROUND

The most reliable method of determining the corrosion rate of a boiler's water-wall tubes is by measuring the tube wall thickness before and after a well defined operating period. At Conesville No. 5, this was accomplished ultrasonically by echoing sound waves through the tubes. The echo time was used to determine the wall thickness of each tube measured.

This nondestructive test was performed at thousands of wall locations inside the furnace. The result was a map of wall thickness within the boiler. Another method involved cutting out old sections of the boiler wall and installing new sections called "corrosion panels," for study.

Both methods required entry into the boiler, which of course, could be done only during an outage with the use of special equipment to reach the test locations. These methods although considerably more difficult than either the furnace gas tap or corrosion probe methods used in this program, yielded results which were more confidently related to true corrosion rate.

## II. EXPERIMENTAL PROCEDURE

The original wall thickness measurements occurred during the December, 1979 outage and included about one thousand points on all four walls at six elevations inside the furnace. (The measurement elevations are shown in Figure B-II-4.) Also during this outage, eight sections (each ten tubes wide (about 2 feet) and 10 feet tall) of the original boiler walls were cut out and replaced with new sections which had been carefully prepared and measured. These new sections, called corrosion panels, consisted of ten tubes, alternately of steel type SA-210 (the usual wall tube material) and T-22 (a material thought to have increased corrosion resistance). Each panel was fabricated with a slot for an inspection door, to allow corrosion probes to be inserted into the furnace.

In November of 1981, nearly two years (12,000 hours of on-line operation) after the initial measurements, the panels and other parts of the walls were remeasured to determine tube wastage rate.

With the exception of a few measurements made by micrometer on the ends of cut tubes, most thickness measurements were performed ultrasonically. The ultrasonic method measures the time required for a sound echo to bounce off the tube's inner surface, and requires careful preparation of the tube's outer surface so that the sound transmitter/receiver may be coupled to it.

Tube surface preparation involved cleaning by motorized wire brush to remove deposits until the white metal of the tube's true outer surface was revealed. Special care was taken* to insure that all surface coatings were removed, without removing any of the tube material itself.

Additionally, the test plan was designed to factor out any bias or change in the corrosion rate that might result from the cleaning procedure. (Some researchers feel that a freshly cleaned surface will corrode faster than an older surface.) This part of the measurement plan was designed to allow for the optional continuation of the test after its scheduled conclusion.

Other steps taken to insure the quality of the data included frequent calibrations, and repeatability tests.

Panel and measurements locations were most heavily concentrated in areas where corrosion was most expected such as at burner elevations, and near corners where the flame comes closest to the walls.

## III. RESULTS

### A. Panel Measurements

The initial panel measurements were made before the panels were installed in the boiler circuit and included thousands of thickness measurements on both the hot and cold sides as well as "on-crown" and "off-crown" eccentricity measurements. Because of economic and scheduling problems, the cold-side, and off-crown measurements were not repeated during the second measurement period.

Before analysis, all raw data from the initial set of measurements was corrected for a systematic calibration error, discovered after those data were collected (see Appendix K).

Figure E-III-1 shows panel geometry and measurement locations for the data reported. Measurement results are summarized in Table E-III-1, and represent the effects of about two years of exposure to the furnace environment (11,640 hours of on-line operation between 12/79 and 11/81). Typically, when on-line, the unit runs at full load from 07:00 till 23:00, and at half load for the remaining early morning hours.

Note that on the average, the panels lost 1.38 mils during the two year exposure period. Dividing by the "on-line" time (11,640 hours) gives a corrosion rate of 1.04 mils per year.

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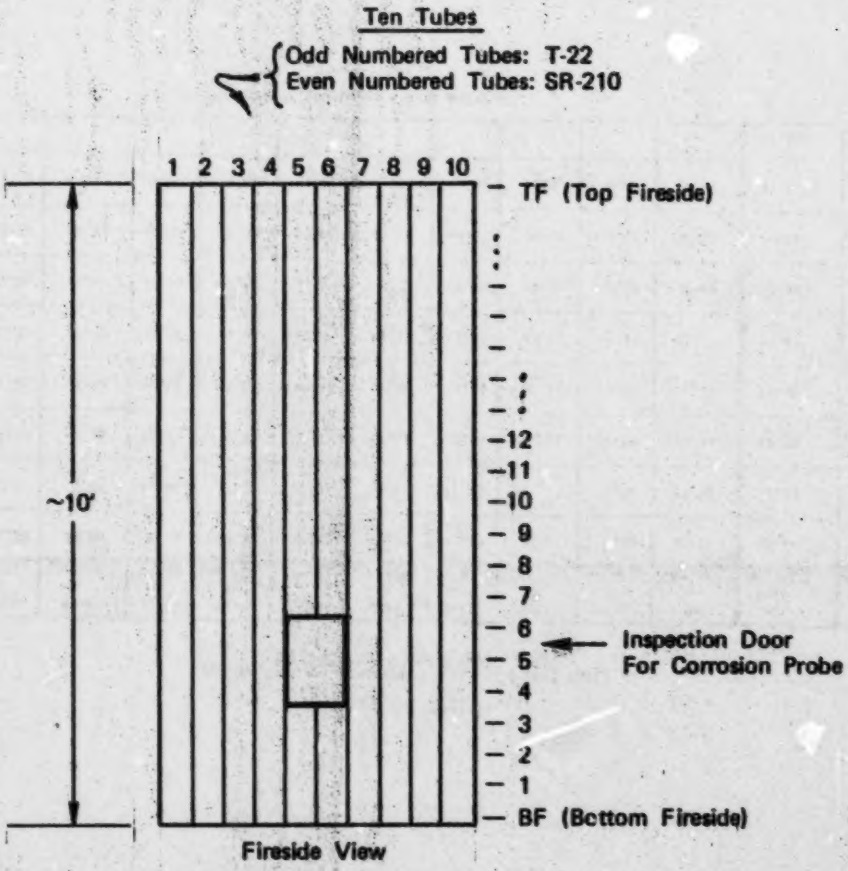
*See Appendix K - "Quality Assurance for Ultrasonic Thickness Data."

Figure E-III-1

CORROSION PANEL GEOMETRY



MEASURED EVERY TUBE, EVERY SIX INCHES
STARTING WITH POINT "BF"

## TABLE E-III-1

### AVERAGE TUBE WALL THICKNESS LOSS FOR PANELS (mil)
("ON-LINE" EXPOSURE TIME = 11,640 HOURS)

| PANEL NO. | PANEL LOCATION | TUBE 1 (T-22) | TUBE 2 (SA-210) | TUBE 3 (T-22) | TUBE 4 (SA-210) | TUBE 5 (T-22) | TUBE 6 (SA-210) | TUBE 7 (T-22) | TUBE 8 (SA-210) | TUBE 9 (T-22) | TUBE 10 (SA-210) | ALL T-22 MATERIAL | ALL SA-210 MATERIAL | AVG. LOSS FOR PANEL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Front wall,<br>wall above burners | +2.39 | +2.39 | -0.64 | +0.42 | +0.59 | +1.01 | -0.25 | +3.11 | -0.02 | +1.14 | +0.41 | +1.05 | +1.03 |
| 2 | Front wall<br>at top burners | +1.92 | +0.83 | +0.91 | +1.66 | +2.14 | +1.91 | +1.15 | +1.27 | +0.81 | +5.32 | +1.39 | +2.20 | +1.80 |
| 3 | Front wall<br>at mid burners | +2.18 | +2.04 | +2.92 | +2.25 | +2.49 | +1.41 | +2.64 | +2.28 | +1.66 | +1.31 | +2.38 | +1.86 | +2.12 |
| 4 | Front wall<br>at bottom burners | +1.26 | +0.72 | +1.81 | +1.68 | +1.54 | +2.88 | +1.85 | +0.61 | +0.94 | +1.11 | +1.48 | +1.40 | +1.44 |
| 5 | Rear wall<br>at top burners | +2.57 | +2.04 | +2.34 | +1.82 | +2.0 | +1.57 | +2.03 | +2.75 | +0.21 | +2.2 | +1.83 | +2.08 | +1.95 |
| 6 | Rear wall<br>at mid burners | +0.26 | +0.92 | +0.77 | +1.04 | +1.2 | +2.21 | +1.12 | +0.83 | +0.08 | +1.48 | +0.69 | +1.3 | +0.99 |
| 7 | Rear wall<br>at bottom burners | -0.36 | +0.63 | +0.02 | +0.39 | +1.07 | +0.62 | -0.05 | +0.40 | -0.67 | +0.52 | -0.04 | +0.51 | +0.24 |
| 8 | Front wall<br>below burners | +1.38 | +1.32 | +1.67 | +0.98 | +1.72 | +1.69 | +1.46 | +2.03 | +0.97 | +1.45 | +1.44 | +1.49 | +1.47 |
| AVG. | | | | | | | | | | | | +1.20 | +1.56 | +1.38* |

*1.38 mils per 11,640 hours = 1.04 mils/yr.

### B. Other UT Wall Thickness Results

In addition to the panel measurements, thousands of other points along the walls were measured in order to produce a map of metal loss throughout the furnace.

Table E-III-2 presents a summary of this metal loss data.

The reader should note that in this boiler (see Figure E-III-2) the flame circulates in a counter clockwise (CCW) direction (from a top view). Hence, the flame comes closest to the higher numbered tubes. (In this discussion, tube numbers run left to right as seen from inside the boiler. This tube numbering system is opposite to CE's system). If the cause of high corrosion is nearness of the flame, then one would expect the highest corrosion rates to occur on the highest numbered tubes on the longest walls (front and rear) in the burner elevations, since this is where the flame comes closest to the walls. However, as the data on Table E-III-2 shows, no such effect was seen.

Another possible effect of the tangential firing system used in this boiler would be unequal corrosion rates on the up-fire and down-fire sides of each tube. One might expect the up-fire side of a tube to corrode faster than the side that was partially shaded from the radiant heat of the burner, thus causing the tube to lose its roundness. To test this theory, some tubes in the burner zone (elevations C, D, and E) on the longest walls (front and rear) were measured for eccentric wear. This was performed by measuring the left and right side of each tube in addition to the usual crown measurement. A summary of the eccentricity measurements is shown on Table E-III-3. The small deviation of the mean from zero, and large scatter of individual data points show that on the average, the tubes wear evenly and maintain their roundness.

## IV. DISCUSSION AND SUMMARY OF CORROSION RESULTS

Corrosion rate was measured by three methods:

- o Corrosion probes
- o Corrosion panels
- o Wall thickness mapping

For the corrosion probes (Table D-III-1), the rate of metal loss seemed to decrease (from more than 70 mils/yr to less than 20 mils/yr) as the exposure time increased, thus, approaching the expected (and actually measured) loss rate for the furnace walls. However, as already mentioned, probes corrode at an accelerated rate, and probe data is useful only for qualitative comparisons. Wall and panel measurements are more representative of the true corrosion rates.

## TABLE E-III-2

## SUMMARY OF METAL LOSS DATA FOR FURNACE WALLS
("ON-LINE" EXPOSURE TIME BETWEEN MEASUREMENTS = 11,640 HOURS)

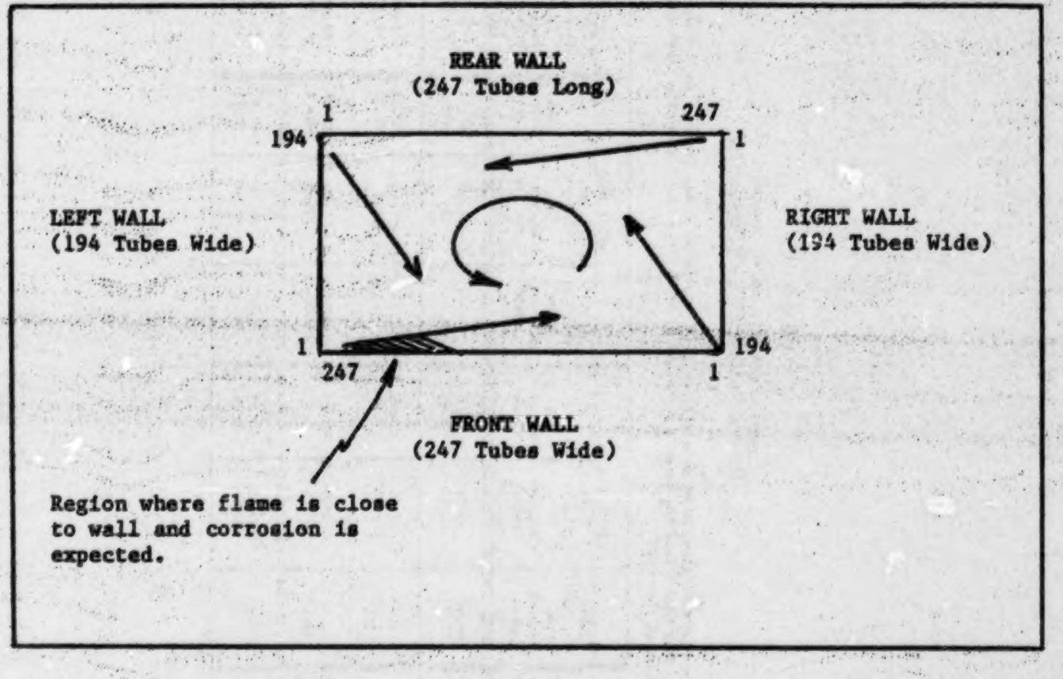
THICKNESS LOSS (mils)

| ELEVATION | | THIRD FARTHEST FROM FLAME | MIDDLE THIRD | THIRD CLOSEST TO FLAME | AVERAGE | |
|---|---|---|---|---|---|---|
| F | FRONT | +2.1 | -0.7 | -0.8 | -0.4 | |
| | RIGHT | -3.1 | -0.9 | -1.7 | +0.9 | |
| (TOP, | REAR | +2.0 | +0.4 | +2.1 | +1.5 | |
| NEAR | LEFT | +2.7 | +2.1 | -1.0 | +1.3 | |
| NOSE) | AVERAGE | +0.9 | +0.2 | -0.4 | +0.8 | |
| E | FRONT | +1.5 | +1.1 | -0.0 | +0.9 | |
| | RIGHT | +1.5 | +3.6 | +2.6 | +2.6 | |
| | REAR | +0.6 | -0.1 | -3.7 | +1.5 | |
| | LEFT | +3.1 | +2.2 | +3.4 | +2.9 | |
| | AVERAGE | +1.7 | +1.7 | +0.6 | +2.0 | |
| D | FRONT | +3.9 | +0.4 | +1.5 | +1.9 | |
| | RIGHT | -3.3 | +1.6 | +4.2 | +0.8 | |
| | REAR | +5.4 | -0.2 | +2.1 | +2.4 | |
| | LEFT | +2.6 | +1.5 | +6.2 | +3.4 | |
| | AVERAGE | +2.2 | +0.8 | +3.5 | +2.1 | |
| C | FRONT | +8.4 | +0.8 | +3.0 | +4.1 | |
| | RIGHT | +0.9 | +0.4 | +2.2 | +1.2 | |
| | REAR | +1.4 | +0.7 | +1.5 | +1.2 | |
| | LEFT | +2.2 | +1.1 | +1.2 | +0.7 | |
| | AVERAGE | +3.2 | +0.5 | +1.4 | +1.8 | |
| B | FRONT | +5.0 | +3.5 | +6.2 | +4.9 | |
| | RIGHT | +1.7 | +7.0 | +5.1 | +4.6 | |
| | REAR | +1.8 | +2.2 | -0.7 | +1.1 | |
| | LEFT | +0.7 | +2.7 | +6.2 | +3.2 | |
| | AVERAGE | +1.4 | +2.8 | -4.5 | +2.9 | |
| A | FRONT | +2.9 | -1.0 | -3.0 | -0.4 | |
| | RIGHT | +0.1 | +1.0 | +0.9 | +0.6 | |
| | REAR | +8.0 | +6.9 | -0.2 | +4.9 | |
| | LEFT | +2.3 | +0.7 | +0.1 | +1.0 | |
| | AVERAGE | +3.3 | +1.2 | -0.6 | +1.5 | |
| AVG | | +2.1 | +1.2 | +1.5 | +1.8 | FRONT |
| | | | | | +1.8 | RIGHT |
| | | | | | +1.7 | REAR |
| | | | | | +2.1 | LEFT |
| GRAND AVERAGE | | | | | +1.85* | |

*1.85 mils per 11,640 hours = 1.39 mils/yr

FIGURE E-III-2

Plan view of furnace showing tube numbering system and zones of closest flame approach.



## TABLE E-III-3

## MEASUREMENT OF ECCENTRIC TUBE WEAR
## (LOSS IN EXCESS OF LEFT SIDE LOSS...MILS)

For each tube, the down-fire side (left side as seen from inside the furnace) was expected to corrode less than either the crown or the up-fire (right) side. This table lists the amounts (in mils) by which the metal loss on the crown and right sides of a tube exceeded the loss on the left side of that tube.

| Elevation | Position | FRONT WALL |  |  | REAR WALL |  |  | BOTH WALLS (AVG) |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  | Tubes Farthest From Burners (Tubes) 1-123 | Tubes Closest To Burners (Tubes) 124-247 | All Tubes (AVG) | Tubes Farthest From Burners (Tubes) 1-123 | Tubes Closest To Burners (Tubes) 124-247 | All Tubes (AVG) | Tubes Farthest From Burners (Tubes) 1-123 | Tubes Closest To Burners (Tubes) 124-247 | All Tubes (AVG) |
| C | Crown<br>Right Side | -4.46<br>-3.73 | -0.18<br>-3.60 | -2.32<br>-3.66 | +2.6<br>+0.1 | +1.50<br>0 | +2.05<br>+0.05 | -0.93<br>-1.82 | +0.66<br>-1.80 | -0.14<br>-1.61 |
| D | Crown<br>Right Side | +1.21<br>+2.15 | +2.10<br>+0.67 | +1.65<br>+1.41 | +0.90<br>+2.60 | -1.15<br>+1.8 | -0.13<br>+2.20 | +1.05<br>+2.37 | +0.48<br>+1.24 | +0.76<br>+1.81 |
| E | Crown<br>Right Side | +1.37<br>-3.27 | +0.63<br>+1.20 | +1.00<br>-1.03 | -0.87<br>+0.57 | +1.03<br>-0.65 | +0.08<br>-0.04 | +0.25<br>-1.35 | +0.83<br>+0.28 | +0.54<br>-0.54 |
| AVG | Crown<br>Right Side | -0.63<br>-1.62 | +0.85<br>-0.58 | +0.11<br>-1.09 | +0.88<br>+1.09 | +0.46<br>+0.38 | +0.67<br>+0.74 | +0.12<br>-0.27 | +0.66<br>-0.09 | +0.39<br>-0.18 |

The corrosion panels (Table E-III-1) had an average loss rate of 1.04 mils per year which compares well with the average wall loss rate (Table E-III-2) of 1.39 mils per year. No correlation was found between corrosion rate and location within the furnace. Furthermore, the T-22 material seemed to corrode at the same rate as the SA-210 material. No eccentric tube wear or loss of roundness was noticed, and the tubes close to the burners did not corrode measurably more than those farther from the flame.

The corrosion rates measured within this boiler were not unlike typical corrosion rates expected for normal boiler operation. And, on the average, if corrosion were to continue at the rate measured in these tests, the normally expected 30 year boiler life would not be limited by wall tube corrosion losses. However, the large scatter in the data indicate that some tubes may corrode significantly faster than the average, and these tubes may be the ones that determine when retubing is required in selected areas.

# PART F

# THIRTY-DAY CONTINUOUS MONITORING OF FLUE-GAS EMISSIONS

(This part of the report summarizes work performed by KVB Inc., a subcontractor to ER&E for this task.)

## I. PURPOSE OF THE THIRTY-DAY TEST

The thirty-day tests were performed with two goals in mind:

- To quantify flue gas emissions during normal load patterns over a period long enough to be representative of long-term operation.
- To evaluate the ability of continuous monitors to perform within the EPA's performance specifications for such monitors.

To these ends a continuous record of 15-minute emission averages (CO, $CO_2$, $O_2$, and $NO_x$) was logged concurrently with boiler operating data over each of the 30-day periods. Also, the continuous emission monitors (CEM) were checked for quality and for compliance with EPA performance specifications PS-2* (for $SO_2$ and $NO_x$ monitors) and PS-3* (for $CO_2$ and $O_2$ monitors). This evaluation included several measurements of drift, accuracy, precision (repeatability), and response time.

## II. EXPERIMENTAL PROCEDURES FOR THE 30-DAY TESTS

Two 30-day tests were performed on the Conesville boiler (Oct.-Nov.1980, and May-June 1981). During each test, boiler load was recorded along with a semi-continuous (once every four seconds) record of stack emissions. Also, at periodic intervals, the performance (zero and span drift, response time, accuracy, etc.) of each continuous emission monitor was evaluated according to EPA procedures to ensure good performance and quality data. The sampling and analysis methods were similar to those described in Part B, Section II of this report. A more detailed description of the experimental procedures used for the 30-day tests may be found in Appendix M.

## III. RESULTS AND DISCUSSION OF THE 30-DAY TESTS

### A. Continuous Monitor Certification Tests

During the two 30-day test periods, the continuous monitor system just described was used to measure the boiler's gaseous emissions. Following shipment to the test site, the monitoring system was installed, and certification tests were performed according to EPA's Performance Specification 2 (PS2) and 3 (PS3), 40 CFR 60.*

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*Code of Federal Regulations (CFR), Title 40 "Protection of the Environment", Part 60 "Standards of Performance for New Stationary Sources" (NSPS), Appendix B "Performance Specifications". Revised July 1, 1982. Pgs. 559-580.

These specifications establish minimum performance criteria that the monitoring system must meet in terms of eight parameters: accuracy, calibration error, two- and 24-hour zero drifts, two- and 24-hour calibration drifts, response time, and operational period.

For the first test, the continuous monitor system was installed and instruments were initially calibrated on October 8, 1980 (for the second test, the corresponding date was May 5, 1981).

The raw data for the CEM performance certification tests are too voluminous for presentation here. However, those data, and the performance of the continuous monitor system are summarized in Table F-III-1. All performance values are in percentage of the span value. Also shown in the table are the monitor specifications extracted from PS2 and PS3. The performance of the CO analyzer, which is not covered by a formal performance specification, is also included on the table. (The CO analyzer is used to monitor the combustion conditions in the boiler since it is a very sensitive indicator of combustion performance.) Table F-III-1 shows that each analyzer in the continuous monitor system performed better in all categories (accuracy, drift, etc.) than is required by the EPA performance specifications.

The results of the relative accuracy determination showed that the NO instrument exceeded the accuracy requirements of PS2. More specifically, during the first 30-day test, the relative accuracy of the Thermo Electron NO analyzer was about 18 percent based on the initial test results, and about 7.9 percent based on the final test series. Similarly, for the second 30-day test, the corresponding relative accuracy numbers were 18.4% and 4.4% based on the initial and final series, respectively. The relative accuracy requirement published in PS2 is $\leq$ 20 percent of mean reference value. Hence, all the experimental values fall within the requirements of the performance specification, and all of the relative accuracy tests showed that the NO instrument exceeded the accuracy requirements of PS2.

## B. Gaseous Emissions Test Results

Summaries of the 24-hour averages for the 30-day test periods are presented in Tables F-III-2 and F-III-3. A partial listing of the 15-minute averages, from which the 24-hour averages were compiled, may be found at the end of Appendix M.

A statistical analysis of the data was performed to determine the distribution characteristics of the 24-hour averages and to calculate the statistical parameters. The normal distribution statistical parameters are presented in Table F-III-4 for all the 24-hour averages, and show, for test 2, for example, that the mean value of stack oxygen content was 5.6 percent with a standard deviation of 0.5 percent, or 9.2 percent of the mean value. The mean NO value (as

## TABLE F-III-1

## INSTRUMENT SPECIFICATIONS AND PERFORMANCE

| Parameter | Specifications | Performance 1st Test | Performance 2nd Test |
|---|---|---|---|
| A. Thermo Electron Series 10 $NO_x$ Analyzer | | | |
| Accuracy | ≤ 20% of mean ref. value | 13.5% | 11.39% |
| Calibration error mid | ≤ 5% of cal gas value | - | 3.71% |
| Calibration error high | ≤ 5% of cal gas value | - | 4.85% |
| Zero drift (2 hour) | 2% of span | 0.57% | 0.07% |
| Zero drift (24 hour) | 2% of span | 0.56% | 0.18% |
| Calibration drift (2 hour) | 2% of span | 0.42% | 0.38% |
| Calibration drift (24 hour) | 2.5% of span | 1.12% | 2.1% |
| Response time | 15 minute maximum | 64 sec | 129 sec |
| Operational period | 168 hour minimum | - | 720 hr |
| B. Horiba Instruments PIR 2000 $CO_2$ Analyzer | | | |
| Zero drift (2 hour) | ≤ 0.4 pct $CO_2$ | 0.21% | <0.1% |
| Zero drift (24 hour) | ≤ 0.5 pct $CO_2$ | 0.24% | 0.04% |
| Calibration drift (2 hour) | ≤ 0.4 pct $CO_2$ | 0.26% | 0.19% |
| Calibration drift (24 hour) | ≤ 0.5 pct $CO_2$ | 0.16% | 0.21% |
| Response time | 10 minutes | 76 sec | 132 sec |
| Operational period | 168 hour minimum | - | 720 hr |
| C. Beckman Instruments Model 742 $O_2$ Analyzer | | | |
| Zero drift (2 hour) | ≤ 0.4 pct $O_2$ | DNA* | DNA* |
| Zero drift (24 hour) | ≤ 0.5 pct $O_2$ | DNA* | DNA* |
| Calibration drift (2 hour) | ≤ 0.4 pct $O_2$ | 0.1% | 0.1% |
| Calibration drift (24 hour) | ≤ 0.5 pct $O_2$ | 0.14% | 0.41% |
| Response time | 10 minutes | 90 sec | 143 sec |
| Operational period | 168 hour minimum | - | 720 hr |
| D. Horiba Instruments PIR 2000 CO Analyzer | | | |
| Calibration error mid | ≤ 5% of cal gas value | - | 2.56% |
| Calibration error high | ≤ 5% of cal gas value | - | 2.48% |
| Zero drift (2 hour) | 2% of span | 0.30% | 0.13% |
| Zero drift (24 hour) | 2% of span | 0.71% | 0.56% |
| Calibration drift (2 hour) | 2% of span | 0.39% | 0.98% |
| Calibration drift (24 hour) | 2.5% of span | 0.77% | 0.89% |
| Response time | 15 minutes | 76 sec | 72 sec |
| Operational period | 168 hour minimum | - | 720 hr |

*Instrument has no zero adjustment.
-No data or data not recorded.

## TABLE F-III-2

## SUMMARY OF DAILY AVERAGE EMISSIONS AND OPERATING DATA
## CONESVILLE UNIT 5 TEST 1

| 24-HOUR DATA DRY STACK GAS CONCENTRATION[a] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Date 1980 | Elec Load $MW_e$ | Therm Load $MW_{th}$ | $O_2$ Vol% | $CO_2$ Vol% | CO PPMV 3% $O_2$ | NO PPMV 3% $O_2$ | CO ng/J | NO ng/J[b] | NO lb/MBtu[b] |
| 10/11 | 266 | 625.2 | 6.1 | 11.6 | 451 | 311 | 161 | 182 | 0.42 |
| 10/12 | 266 | 556.2 | 6.9 | 11.3 | 777 | 341 | 277 | 200 | 0.47 |
| 10/13 | 160 | 502.1 | 7.4 | 11.1 | 914 | 440 | 326 | 258 | 0.6 |
| 10/14 | 257 | 553.8 | 6.1 | 12.5 | 634 | 340 | 226 | 199 | 0.46 |
| 10/15 | 215 | 489.6 | 6.1 | 11.8 | 431 | 371 | 154 | 218 | 0.51 |
| 10/16 | 154 | 415 | 6.5 | 11.9 | 381 | 395 | 136 | 231 | 0.54 |
| 10/17 | 278 | 572.6 | 6 | 12.3 | 376 | 363 | 134 | 213 | 0.5 |
| 10/18 | 287 | 419.1 | 5.7 | 12.4 | 379 | 372 | 135 | 218 | 0.51 |
| 10/19 | 199 | 536.5 | 6.4 | 12.2 | 503 | 412 | 179 | 242 | 0.56 |
| 10/20 | 305 | 646 | 5.8 | 12.4 | 652 | 342 | 233 | 201 | 0.47 |
| 10/21 | 315 | 600.5 | 5.8 | 12.3 | 433 | 397 | 154 | 233 | 0.54 |
| 10/22 | 252 | 525.6 | 6.7 | 11.8 | 280 | 385 | 100 | 226 | 0.53 |
| 10/23 | 294 | 613.3 | 6.4 | 12.5 | 268 | 384 | 96 | 225 | 0.52 |
| 10/24 | 281 | 573.1 | 6.4 | 12 | 356 | 373 | 127 | 219 | 0.51 |
| 10/25 | 300 | 409.1 | 6.8 | 10.8 | 502 | 288 | 179 | 169 | 0.39 |
| 11/06[c] | 147 | 311.4 | 7.8 | 10.7 | 207 | 409 | 73 | 240 | 0.56 |
| 11/12[d] | 156 | 340.9 | 7.8 | 10.6 | - | 433 | - | 254 | 0.59 |
| 11/13 | 160 | 603.9 | 7.9 | 10.8 | 90 | 440 | 32 | 258 | 0.6 |
| 11/14 | 161 | 490.1 | 8.4 | 10.5 | - | 440 | - | 258 | 0.6 |
| 11/15 | 171 | 337.3 | 8.2 | 10.5 | 87 | 401 | 31 | 235 | 0.55 |
| 11/16 | 140 | 335.7 | 8.4 | 10.5 | 692 | 348 | 247 | 204 | 0.47 |
| 11/17 | 141 | 336 | 8.6 | 10.2 | 789 | 396 | 282 | 232 | 0.54 |
| 11/18 | 171 | 395.5 | 7.2 | 11.2 | - | 450 | - | 263 | 0.61 |
| 11/19 | 201 | 428.3 | 7.2 | 11.2 | 111 | 428 | 40 | 252 | 0.59 |
| 11/20 | 213 | 458.4 | 7.5 | 11 | 135 | 418 | 48 | 245 | 0.57 |
| 11/21 | 208 | 464.4 | 7.6 | 11 | 21 | 422 | 7 | 247 | 0.56 |
| 11/24[e] | 156 | 561.8 | 5.8 | 12.4 | - | 303 | - | 178 | 0.41 |
| 11/25 | 194 | 611.3 | 6.5 | 11.8 | - | 360 | - | 211 | 0.49 |
| 11/26 | 334 | 518.8 | 6.6 | 11.8 | - | 358 | - | 210 | 0.49 |

[a] "-" (dash) indicates missing data.

[b] As $NO_2$

[c] Oct. 26 through Nov. 5: $NO_x$ instrument vacuum pump failure.

[d] Nov. 7 to Nov. 11: Sample pump and sample line problems.

[e] Nov. 22 and Nov. 23: Boiler down for scheduled maintenance.

## TABLE F-III-3

## SUMMARY OF DAILY AVERAGE EMISSIONS AND OPERATING DATA
## CONESVILLE UNIT 5 TEST 2

24-HOUR DATA
DRY STACK GAS CONCENTRATION

| Date 1980 | Elec Load $MW_e$ | Therm Load $MW_{th}$ | $O_2$ Vol% | $CO_2$ Vol% | CO PPMV 3% $O_2$ | NO PPMV 3% $O_2$ | CO ng/J | NO ng/J[a] | NO lb/MBtu[a] |
|---|---|---|---|---|---|---|---|---|---|
| 5/5 | 345 | 801.9 | 4.5 | 13.2 | 54 | 284 | 19 | 166 | 0.39 |
| 5/6 | 308 | 638 | 4.9 | 12.5 | 33 | 272 | 11 | 159 | 0.37 |
| 5/7 | 328 | 688.1 | 5.1 | 12.3 | 41 | 296 | 14 | 173 | 0.43 |
| 5/8 | 328 | 692.7 | 6.2 | 11.7 | 31 | 328 | 11 | 192 | 0.45 |
| 5/9 | 293 | 614.4 | 5.8 | 11.5 | 33 | 320 | 11 | 188 | 0.44 |
| 5/10[b] | 232 | 492.1 | 6.5 | 10.7 | 34 | - | 12 | - | -[b] |
| 5/11 | 381 | 717.1 | 5.2 | 12.4 | 47 | 343 | 17 | 201 | 0.47 |
| 5/12 | 313 | 650.4 | 5.4 | 12.1 | 52 | 308 | 18 | 180 | 0.42 |
| 5/13 | 310 | 649.6 | 5.4 | 11.9 | 44 | 309 | 16 | 181 | 0.42 |
| 5/14 | 360 | 718.7 | 5.3 | 11.9 | 44 | 321 | 15 | 188 | 0.44 |
| 5/15 | 300 | 587.9 | 5.7 | 12.2 | 57 | 306 | 20 | 179 | 0.42 |
| 5/16 | 280 | 595.4 | 6.1 | 11.7 | 65 | 300 | 23 | 176 | 0.41 |
| 5/17 | 228 | 484.6 | 7 | 10.5 | 65 | 332 | 23 | 195 | 0.45 |
| 5/18 | 339 | 718.2 | 5.8 | 11.6 | 61 | 334 | 21 | 196 | 0.46 |
| 5/19 | 345 | 726 | 5.6 | 12 | 56 | 321 | 19 | 188 | 0.44 |
| 5/20 | 350 | 731.9 | 5.7 | 12.4 | 79 | 329 | 28 | 193 | 0.45 |
| 5/21 | 337 | 729.4 | 5.8 | 12.3 | 135 | 329 | 48 | 193 | 0.45 |
| 5/22 | 342 | 740.8 | 5.5 | 12 | 122 | 360 | 43 | 211 | 0.49 |
| 5/23 | 329 | 688 | 5.6 | 12 | 36 | 335 | 12 | 196 | 0.46 |
| 5/24 | 297 | 631.1 | 5.7 | 12 | 27 | 343 | 9 | 201 | 0.47 |
| 5/25 | 289 | 633.4 | 5.6 | 12.1 | 28 | 286 | 10 | 157 | 0.39 |
| 5/26 | 321 | 676 | 5.4 | 12.2 | 23 | 299 | 8 | 176 | 0.41 |
| 5/27 | 197 | 445.1 | 6.7 | 11 | 16 | 381 | 5 | 223 | 0.52 |
| 5/29 | 314 | 660 | 4.9 | 12.7 | 30 | 292 | 10 | 171 | 0.4 |
| 5/30 | 361 | 759.8 | 5.3 | 12.3 | 33 | 324 | 11 | 190 | 0.44 |
| 5/31 | 299 | 641.9 | 5.7 | 11.9 | 38 | 274 | 13 | 161 | 0.37 |
| 6/1 | 337 | 724.8 | 5.6 | 11.9 | 42 | 300 | 15 | 176 | 0.41 |
| 6/2 | 356 | 729.8 | 5.4 | 12.1 | 54 | 300 | 19 | 176 | 0.41 |
| 6/3 | 265 | 558.8 | 6.4 | 11.2 | 80 | 314 | 28 | 184 | 0.43 |
| 6/4 | 363 | 695.9 | 5.5 | 12.2 | 67 | 317 | 24 | 186 | 0.43 |
| 6/5 | 340 | 710.4 | 5 | 12.8 | 50 | 268 | 18 | 157 | 0.37 |
| 6/6 | 321 | 670.4 | 5 | 12.4 | 43 | 233 | 15 | 137 | 0.32 |
| 6/7 | 231 | 486.3 | 6.3 | 11.2 | 42 | 280 | 15 | 164 | 0.38 |
| 6/8 | 243 | 479.4 | 5.5 | 11.7 | 35 | 299 | 12 | 175 | 0.41 |
| 6/9 | 336 | 618.3 | 5.9 | 11.4 | 26 | 307 | 9 | 180 | 0.42 |

[a] As $NO_2$
[b] 5/10: NO analyzer out of service. Dash ("-") indicates missing data.

## TABLE F-III-4

## STATISTICAL PARAMETERS FOR CONESVILLE UNIT NO. 5
## 30-DAY FIELD TESTS

First 30-Day Test

| | Load ($MW_{th}$) | $O_2$ (%) | $CO_2$ (%) | CO (ppm)* | CO (ng/J) | NO (ppm)* | NO ng/J | NO (lbs/MBtu)** |
|---|---|---|---|---|---|---|---|---|
| Mean | 490.7 | 6.9 | 11.5 | 320 | 114 | 387 | 226 | 0.526 |
| Minimum | 646.0 | 5.7 | 10.2 | 0 | 0 | 303 | 177 | 0.412 |
| Maximum | 311.4 | 8.6 | 12.5 | 914 | 329 | 447 | 261 | 0.607 |
| Range | 334.6 | 2.9 | 2.3 | 914 | 329 | 144 | 84 | 0.195 |
| Standard Deviation | 101.1 | 0.9 | 0.7 | 280 | 100 | 40 | 23 | 0.053 |
| Percent Deviation | 20.6 | 13.0 | 6.1 | 87.5 | 87.5 | 10.3 | 10.3 | 10.3 |
| Variance | 10,214 | 0.81 | 0.49 | 78400 | 10000 | 1600 | 52.9 | 1.230 |
| Count | 29 | 29 | 29 | 29 | 29 | 29 | 29 | 29 |

Second 30-Day Test

| | Load ($MW_{th}$) | $O_2$ (%) | $CO_2$ (%) | CO (ppm)* | CO (ng/J) | NO (ppm)* | NO ng/J | NO (lbs/MBtu)** |
|---|---|---|---|---|---|---|---|---|
| Mean | 647.2 | 5.63 | 11.94 | 49.2 | 17.2 | 310.1 | 182.1 | 0.42 |
| Minimum | 445.1 | 4.5 | 10.5 | 14 | 5.0 | 233 | 137.0 | 0.32 |
| Maximum | 801.9 | 7.0 | 13.2 | 135 | 48.0 | 381 | 223.0 | 0.52 |
| Range | 356.8 | 2.5 | 2.7 | 121 | 43.0 | 148 | 86.0 | 0.20 |
| Standard Deviation | 87.7 | 0.524 | 0.558 | 25.07 | 8.86 | 28.46 | 16.32 | 0.04 |
| Percent Deviation | 13.6 | 9.3 | 4.7 | 52.0 | 52.0 | 9.0 | 9.0 | 9.0 |
| Variance | 7693.0 | 0.275 | 0.312 | 628.6 | 78.56 | 96172 | 266.3 | 0.0016 |
| Count | 35 | 35 | 35 | 35 | 35 | 34 | 34 | 34 |

*Corrected to 3% $O_2$, dry.
**As $NO_2$.

equivalent $NO_2$) was 182.1 ng/J with a standard deviation of 16.3, or 9.0 percent of the mean value.

The 24-hour average data were plotted as a function of time from the start of testing. Figure F-III-1 shows the variation in boiler thermal and electric load as a function of time from the start of the first test, during which the average thermal load varied from approximately 75 percent of rated capacity to 37 percent, and the daily average electrical output had a mean value of 220 $MW_e$ or 54 percent of rated capacity. The daily averages used in this figure were obtained from the unit operators. The two curves do not always match and the reason is not clear. The most obvious mismatch is about the eighteenth or nineteenth days where the steam flow is high and the electrical output is low.

Similarly, the thermal and electric load data for the second test are shown on Figure F-III-2. Here, the daily average boiler load varied from a minimum of 445 $MW_{th}$ to 802 $MW_{th}$, and the average electric output for the test period was 75% of rated capacity.

Figures F-III-3 through F-III-8 show the gaseous emissions as a function of time for these two test periods. The drift and scatter of the CO data were large during the first test (see Appendix M "Data Quality"). However, for the second test, even though the CO emissions rate continued to show a wide variation, the maximum value on the graph (Fig. F-III-7) is still quite small (48 ng/J or 135 ppm). The $O_2$, $CO_2$, and NO emissions rates were fairly stable over the period of both tests.

The boiler stack excess oxygen and NO emission rate as a function of time from the start of testing are shown in Figures F-III-3 and F-III-4, respectively, for the first test, and Figures F-III-5 and F-III-6 for the second. (Similarly, $CO_2$ vs. time and $CO_2$ vs. $O_2$ are shown in Figures F-III-7 and F-III-8, respectively.) In general, the periods of high excess $O_2$ correspond to periods of low boiler load. The effects of boiler load on excess oxygen (an independently controlled effect) and on NO emission rates are shown in Figures F-III-9 and F-III-10 for the first test, and Figures F-III-11 and F-III-12 for the second test. Generally, one would expect the $NO_x$ emission rate (expressed in "ng/J") to decrease as load decreases due to the cooler temperatures inside the furnace at the lower loads. However, as load is decreased, the amount of excess air is increased (for operational safety and stability), and this tends to increase the $NO_x$ production. The two effects together tend to nullify each other, and the $NO_x$ vs. load trend lines (Figs. F-III-10 and F-III-12) are nearly horizontal.

The NO emission rate vs. stack excess oxygen (without consideration of load, etc.) is presented in Figures F-III-13 and F-III-14. Although there is considerable scatter in the data, the trend is for an increase in NO emissions with increasing excess oxygen. However,

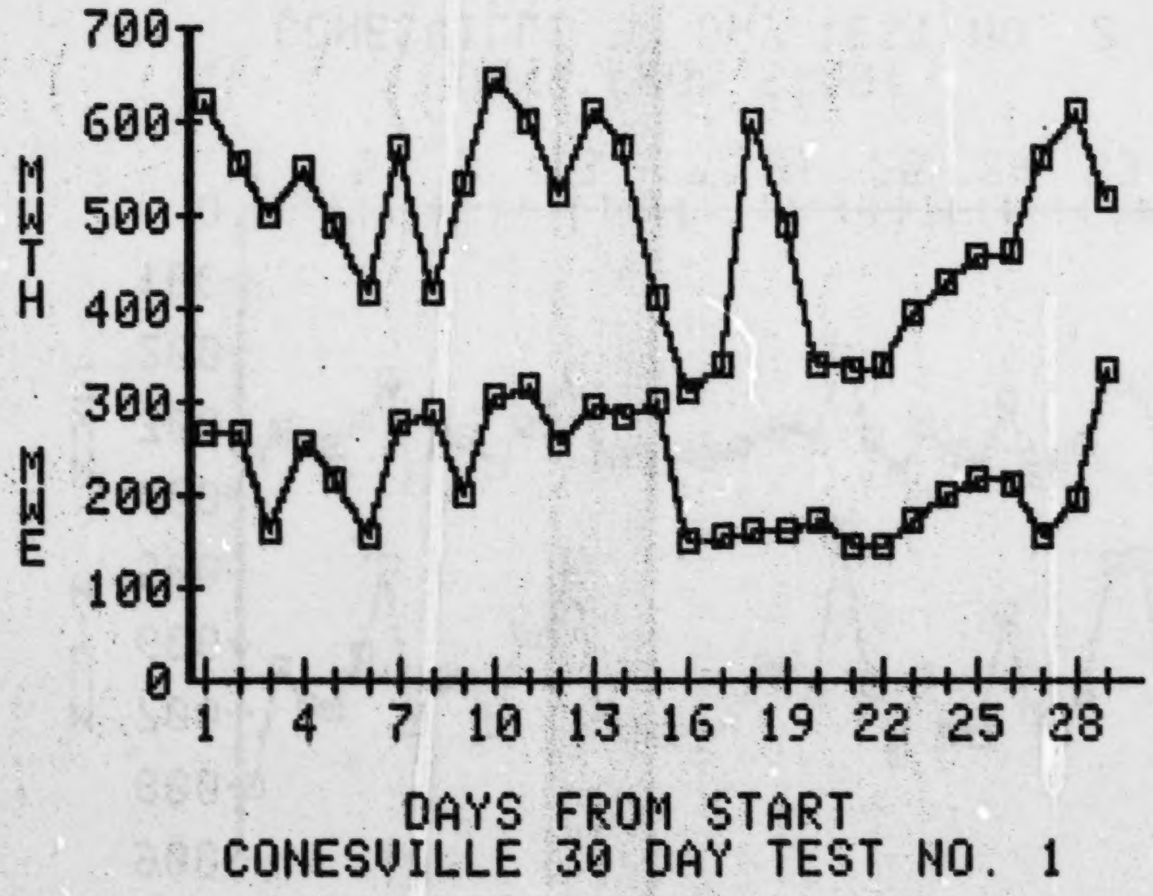

**Figure F-III-1.** Test No. 1: Daily Average Electrical Output and Boiler Thermal Load as a Function of Time

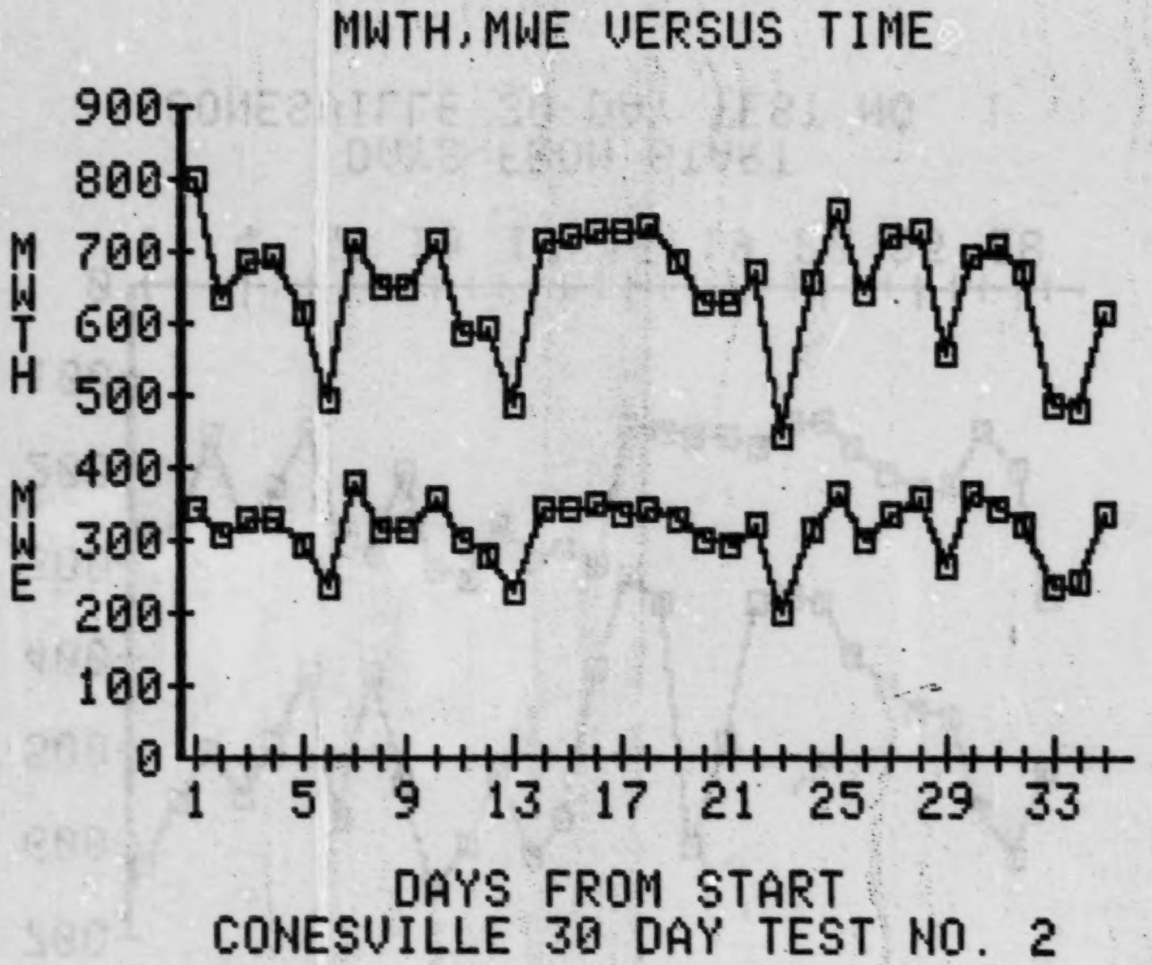

Figure F-III-2. Test No. 2: Comparison of Average Steam Load and Electrical Generator Output

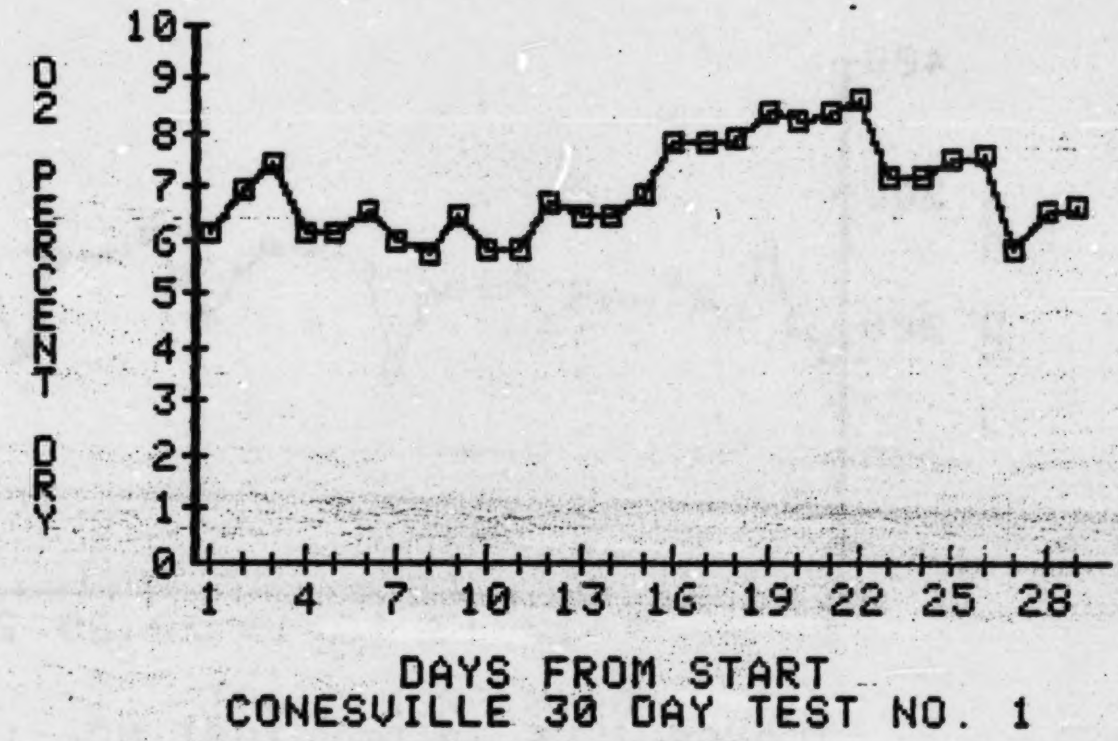

Figure F-III-3. Test No. 1: Daily Average Stack Oxygen Concentration as a Function of Time

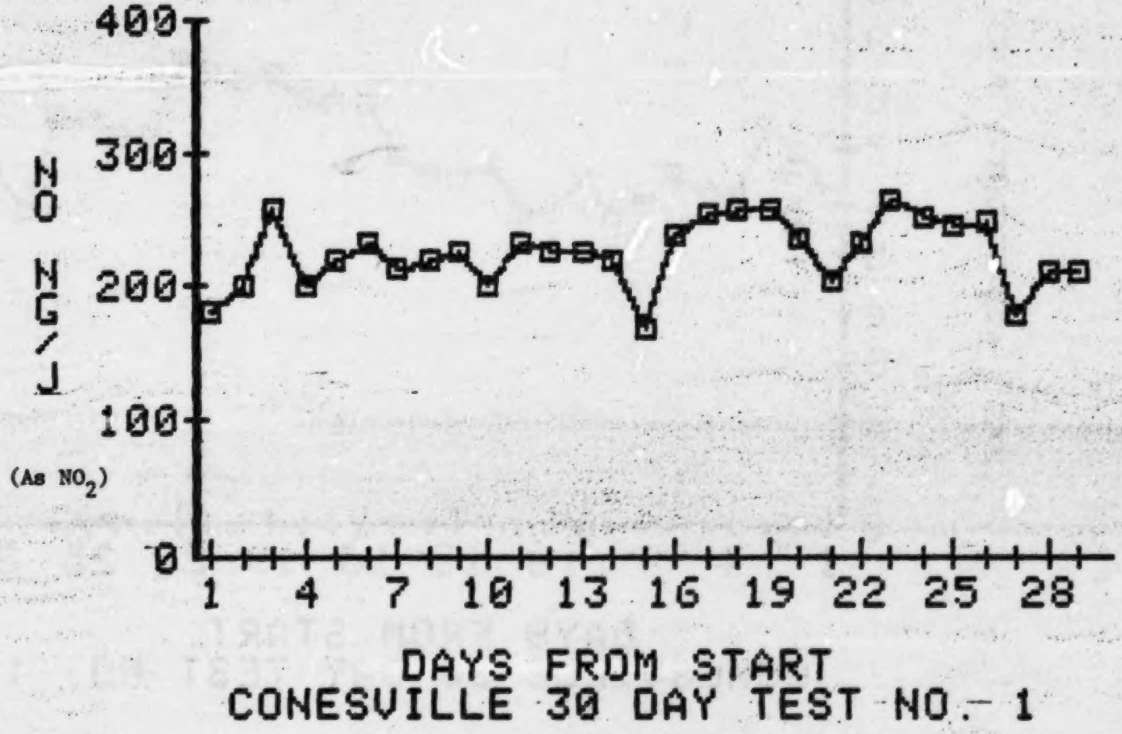

Figure F-III-4. Test No. 1: Daily Average NO Concentration as a Function of Time

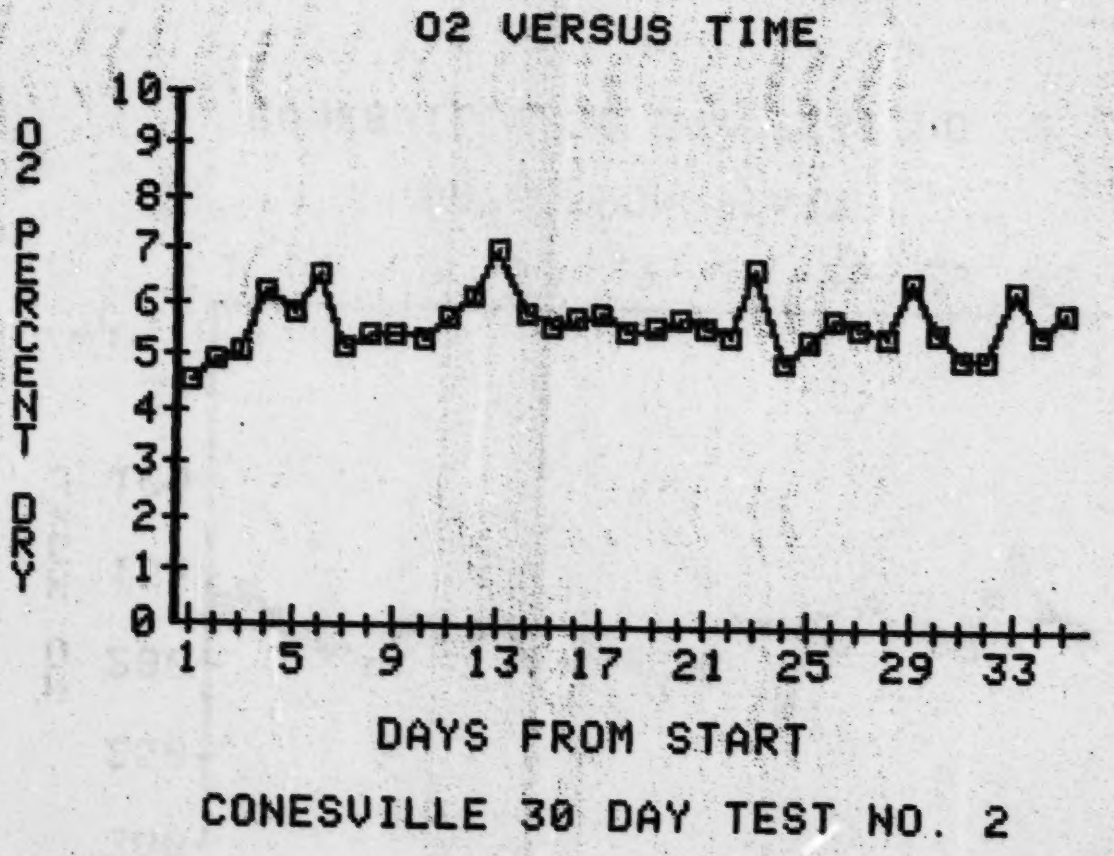

Figure F-III-5. Test No. 2: Daily Average $O_2$ as a Function of Time

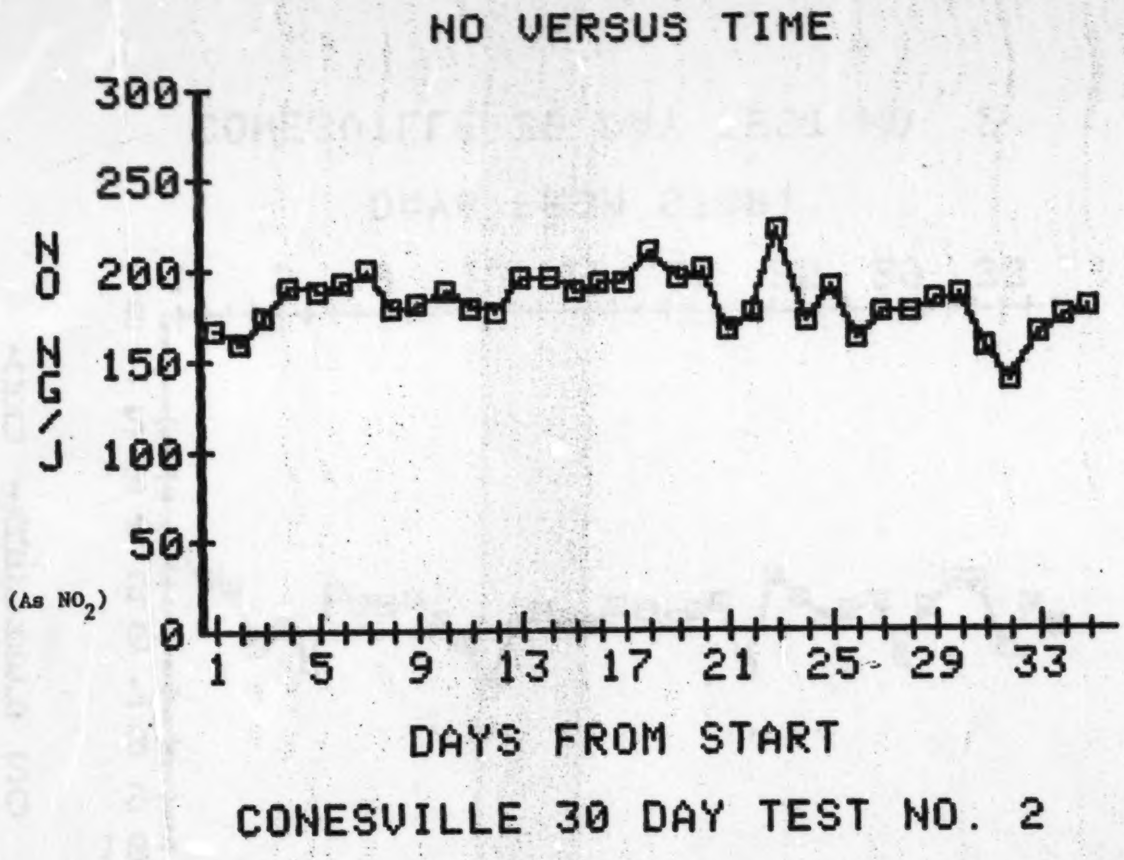

Figure F-III-6. Test No. 2: Daily Average NO Emission Rate as a Function of Time

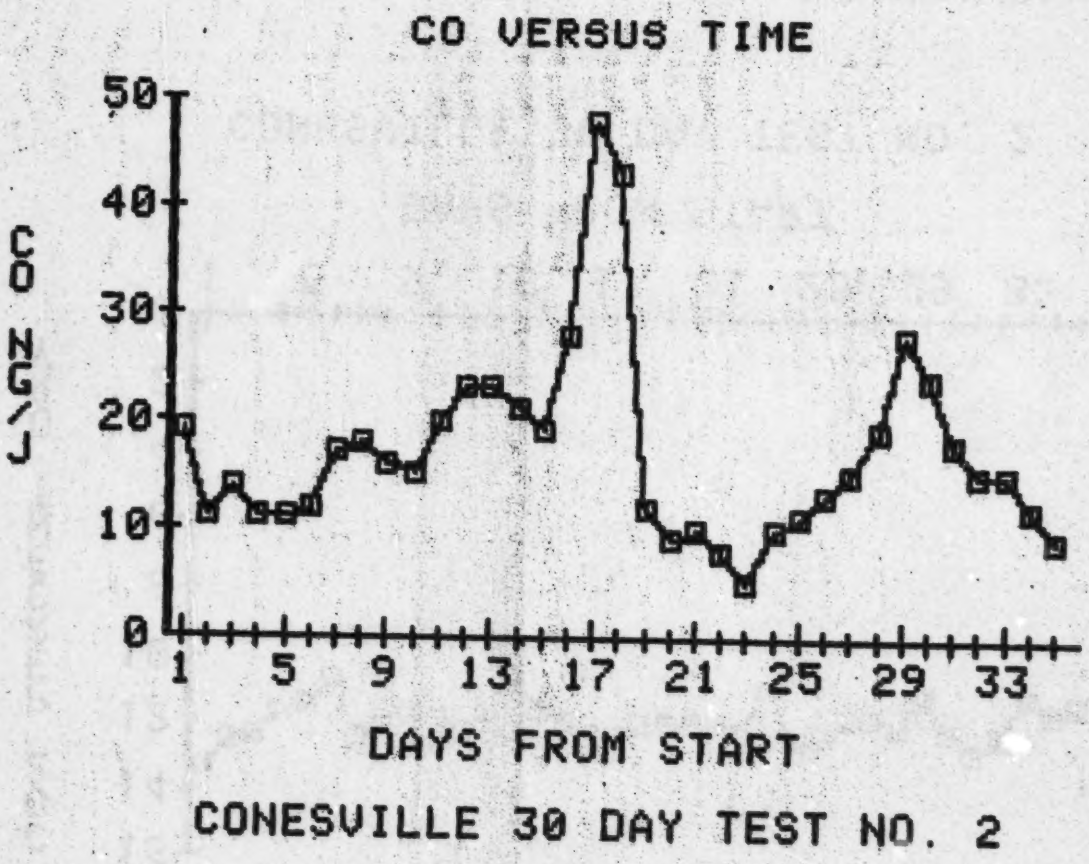

Figure F-III-7. Test 2: Daily Average CO Emission Rate as a Function of Time

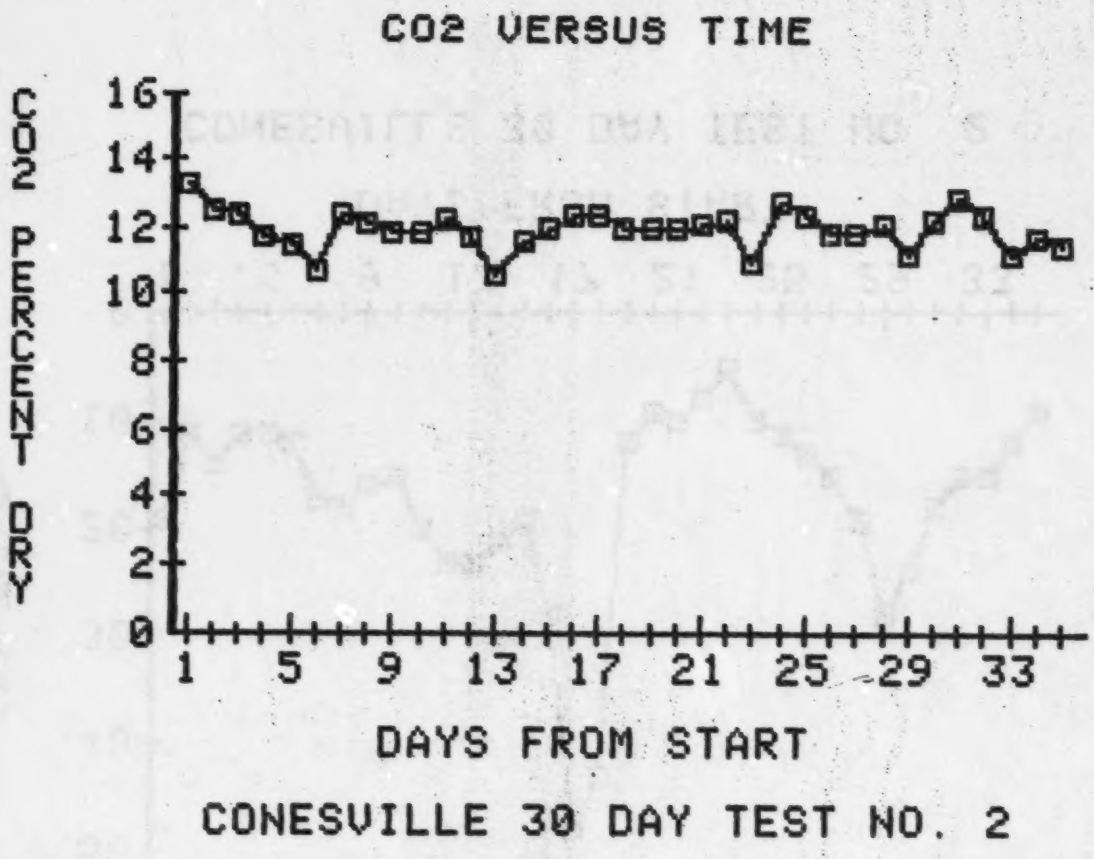

Figure F-III-8. Test 2: Daily Average $CO_2$ as a Function of Time

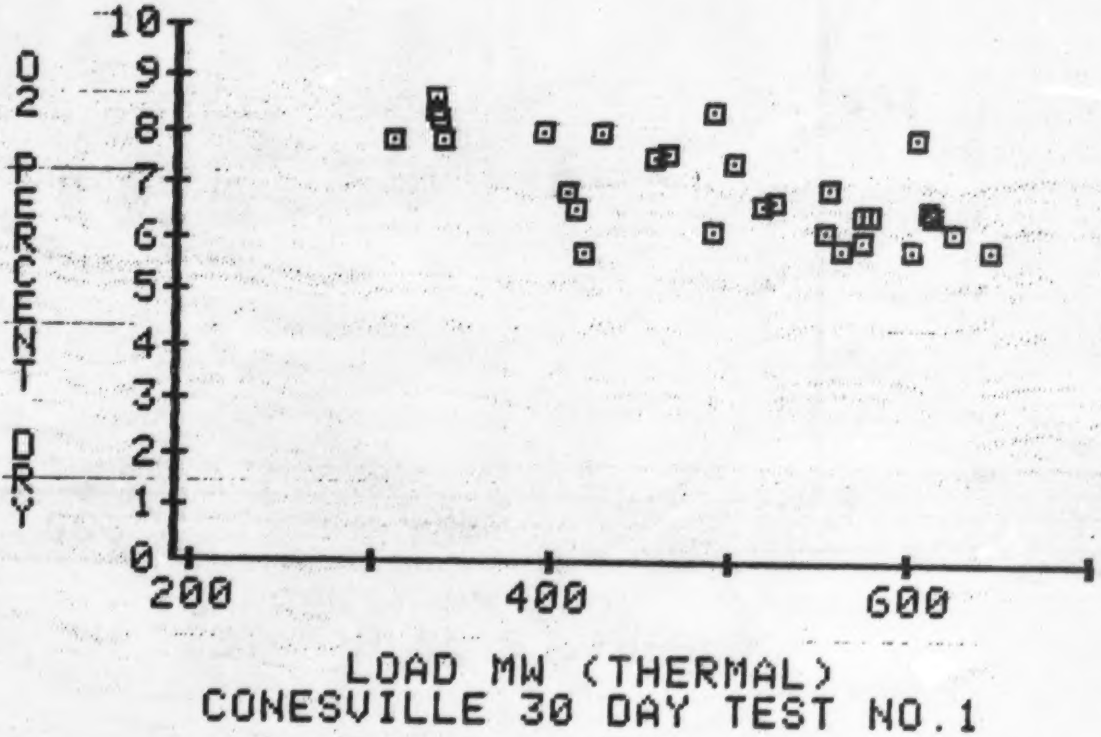

**Figure F-III-9.** **Test No. 1: Stack Oxygen Concentration as a Function of Boiler Steam Load**

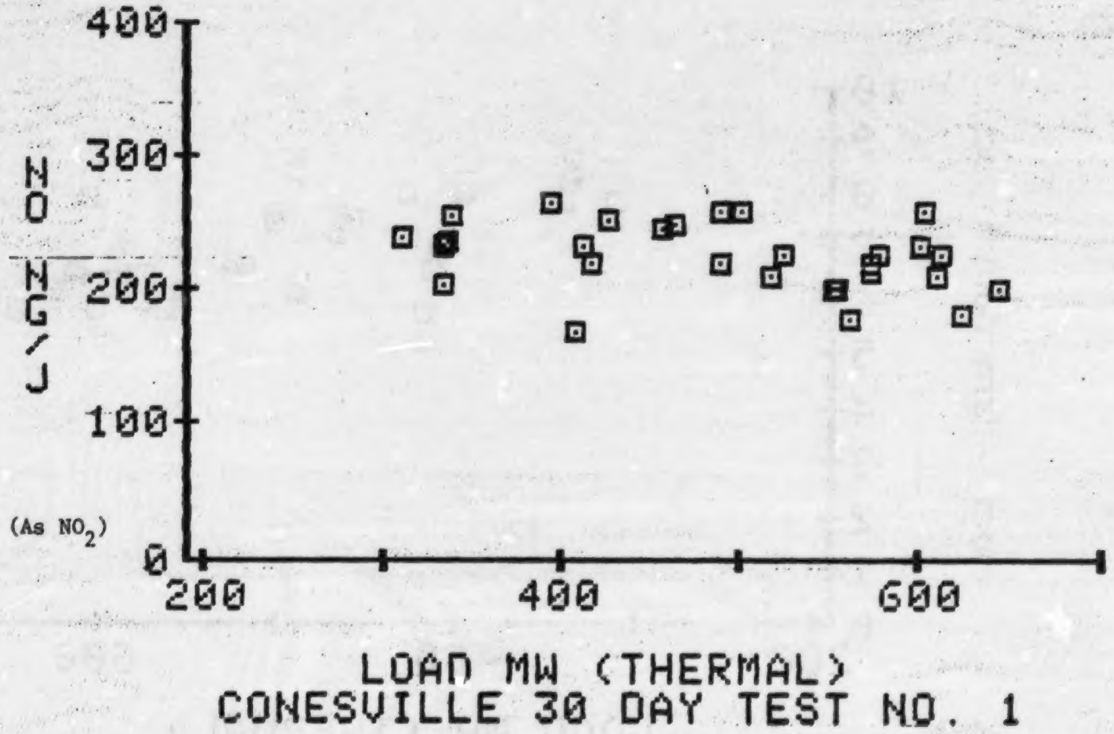

Figure F-III-10. Test No. 1: Daily Average NO Concentration as a Function of Boiler Steam Load

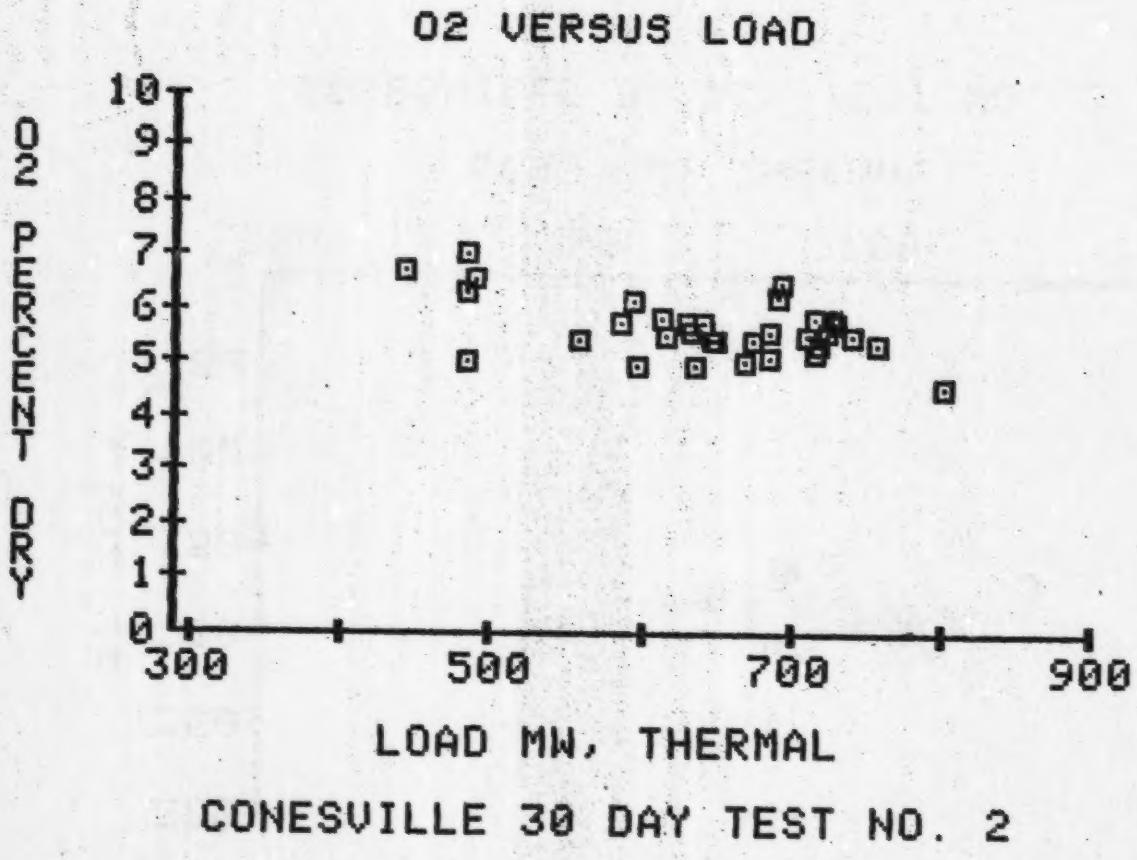

Figure F-III-11. Test No. 2: The Effect of Boiler Load on Stack Excess Oxygen

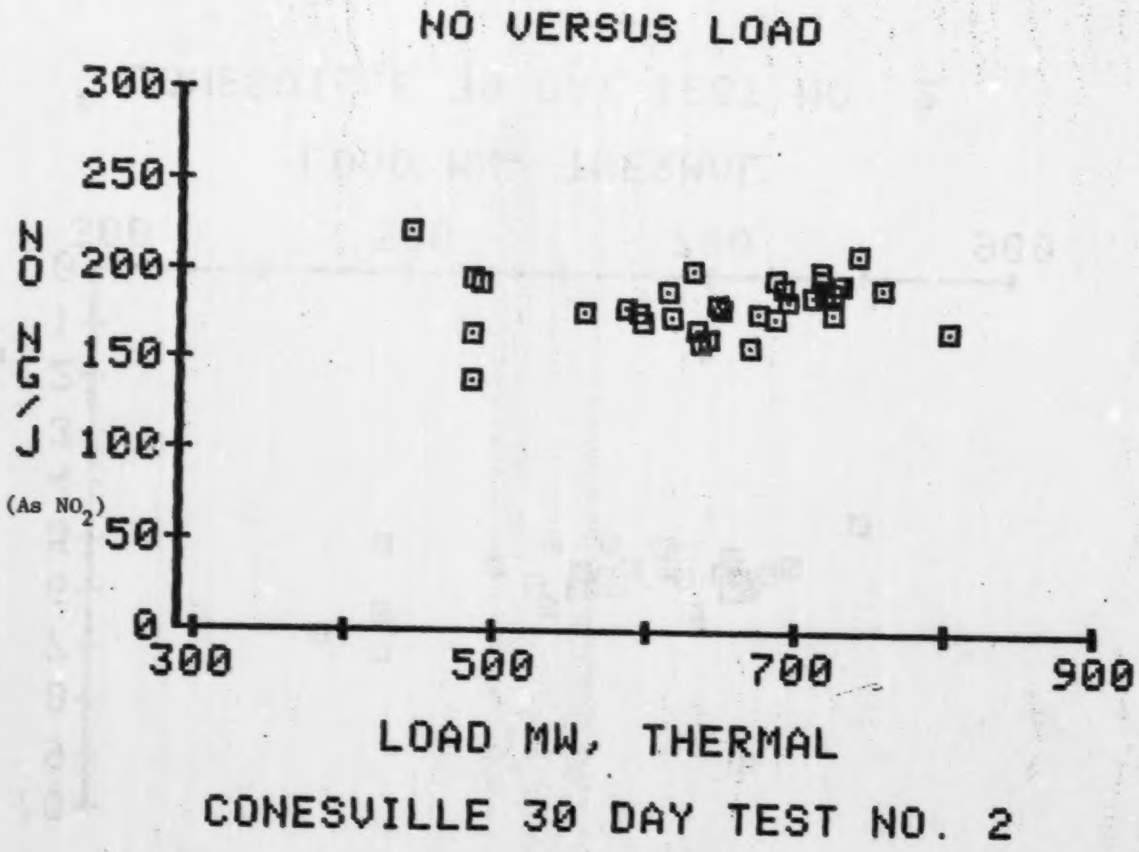

Figure F-III-12. Test No. 2: The Effect of Boiler Load on NO Emission Rate

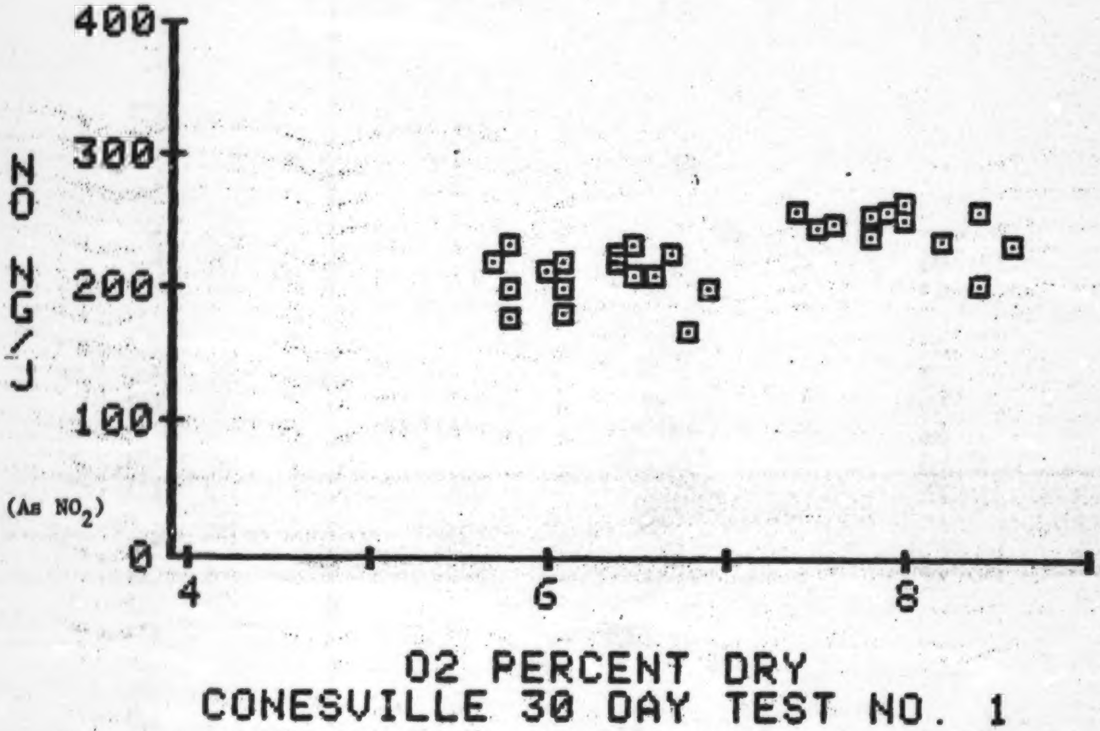

**Figure F-III-13.** Test No. 1: Daily Average NO Concentration as a Function of Stack Oxygen Content

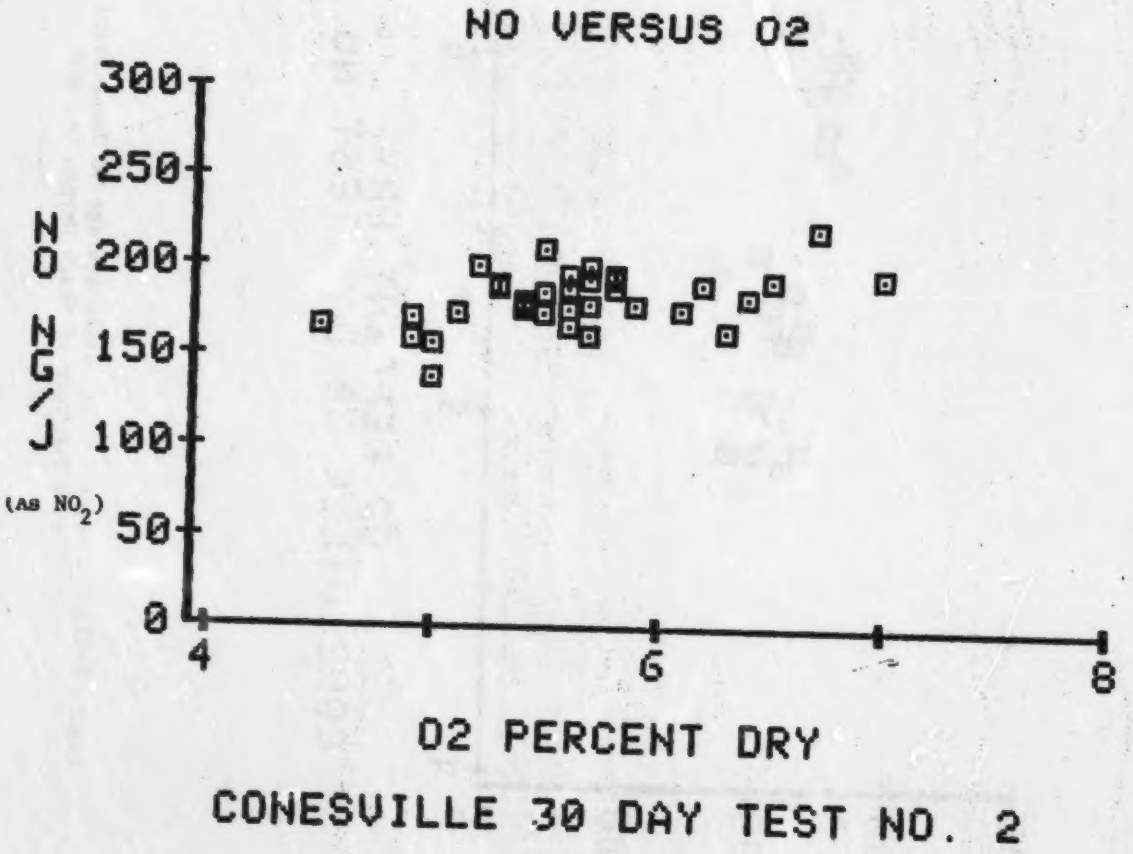

Figure F-III-14. Test No. 2: The Effect of Excess Stack $O_2$ on NO Emission Rate this trend is tempered by the fact that increased oxygen concentration (a $NO_x$ promoter) occurs most often at low loads (a $NO_x$ retardant). Consequently, the $NO_x$ vs. $O_2$ curves shown here (which include all loads) have a shallower slope than the curves shown in Part B of this report (where the data was separated by load before being plotted).

A linear regression analysis performed on some of the data from the second CEM test indicated that the "$O_2$ vs. Load" data (Fig. F-III-11) could not be defined with a linear curve fit. (Hence, no line has been drawn through the data points.)

Some of the statistical data (Table F-III-4) are shown graphically, (plots of normal probability and log-normal probability) in Figures F-III-15 through F-III-18. For the first test, the normal probability plot (NO vs. probability) shows a good fit to the data (Fig. F-III-15). The data were also plotted on log-probability coordinates as shown in Figure F-III-16. This plot shows that the mean* NO value is 224 ng/J with a geometric dispersion* of 1.13. Both graphical distributions show mean values of 224 ng/J, which agrees quite well with the calculated value of 227 ng/J. For the normal distribution, 99 percent of the values are less than 292 ng/J while the log-normal distribution indicated that 99 percent of the values are less than 300 ng/J.

A similar exercise for the data from the second CEM test shows clearly (Fig. F-III-17) that the data are not normally distributed. (Normal distribution of data would result in a straight line when plotted on probability paper.) The data were then plotted on log-probability paper as shown in Figure F-III-18. These data result in a straight line which indicates that the data are log-normally distributed. Examination of this figure shows that the mean value is 180 ng/J. The calculated log mean value is 182 ng/J. The geometric dispersion, which is analogous to a normal distribution standard deviation, was calculated to be 1.12. This figure shows that 99 percent of the data would be less than 230 ng/J (0.53 lb/MBtu).

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*The mean is the y-intercept at the 50 percent value. The geometric dispersion or geometric standard deviation is the ratio of the 93.3 percent and 6.7 percent "less than" values, raised to the 1/3 power.

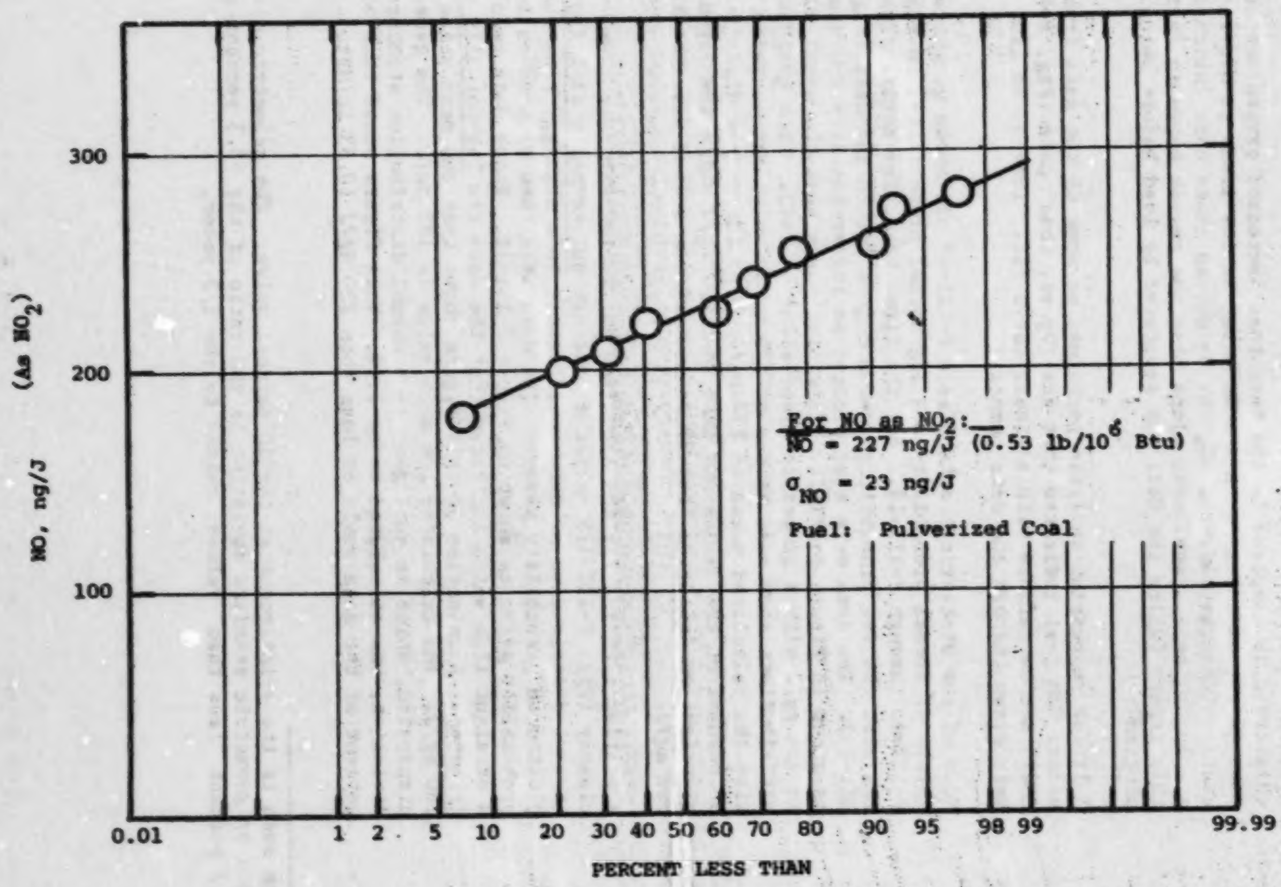


Figure F-III-15. Normal probability curve of NO emission rate for Conesville Unit No. 5, Test No. 1.

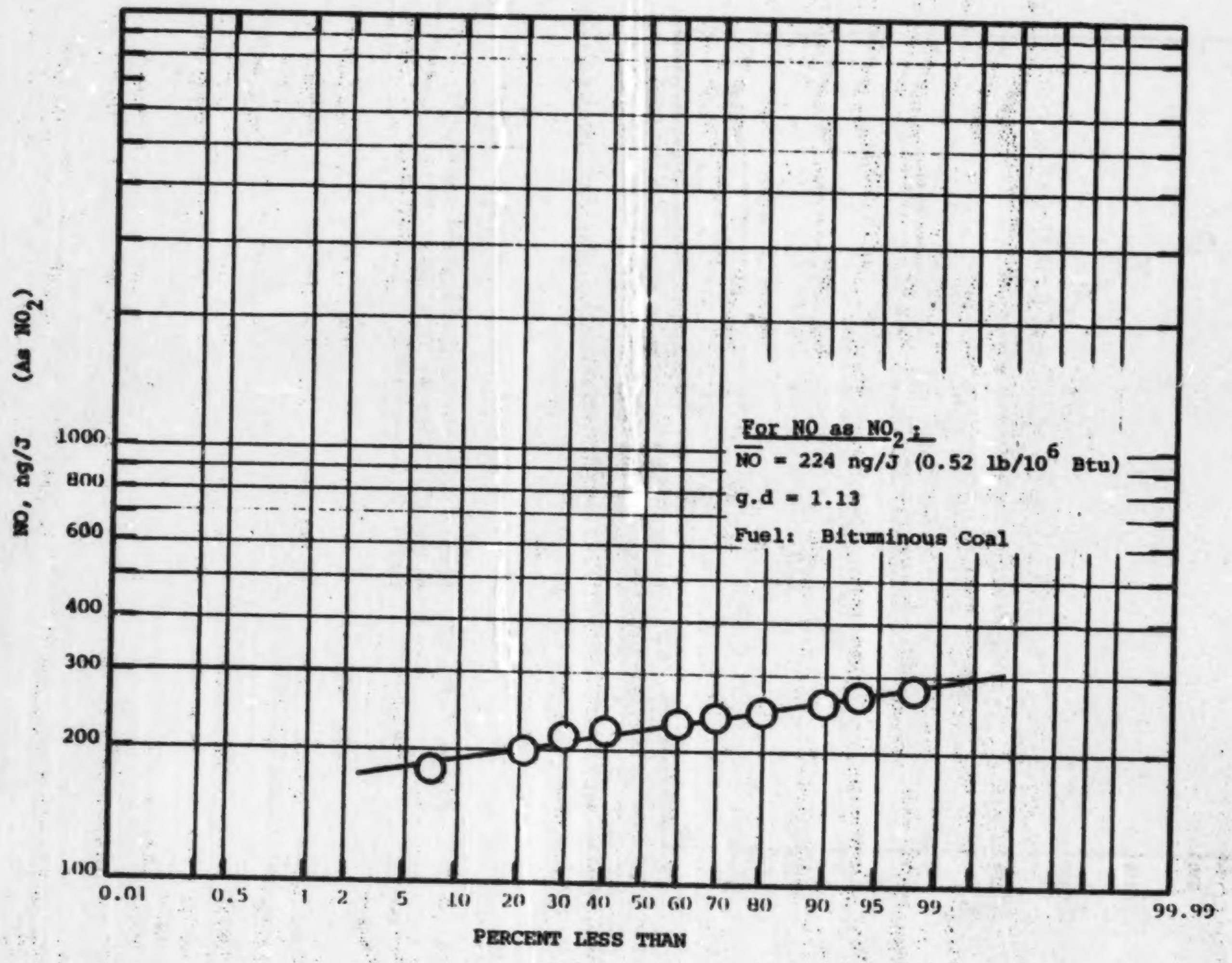


Figure F-III-16. Log probability curve of NO emission rate for Conesville Unit No. 5, Test No. 1.

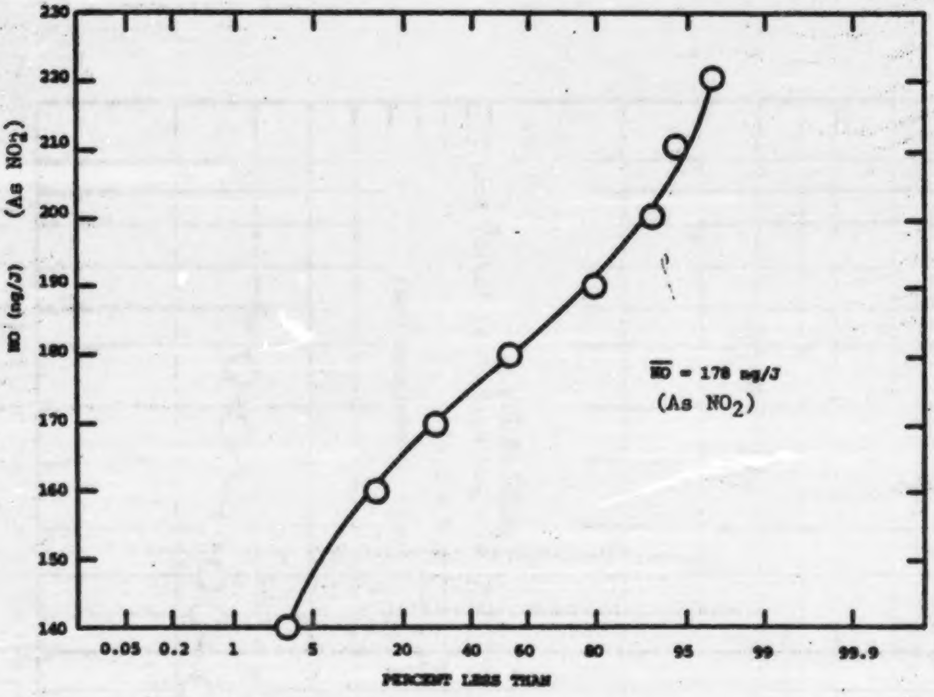


Figure F-III-17. Normal probability curve of NO emissions
Conesville Unit 5, Test No. 2
May 5 - June 9, 1981

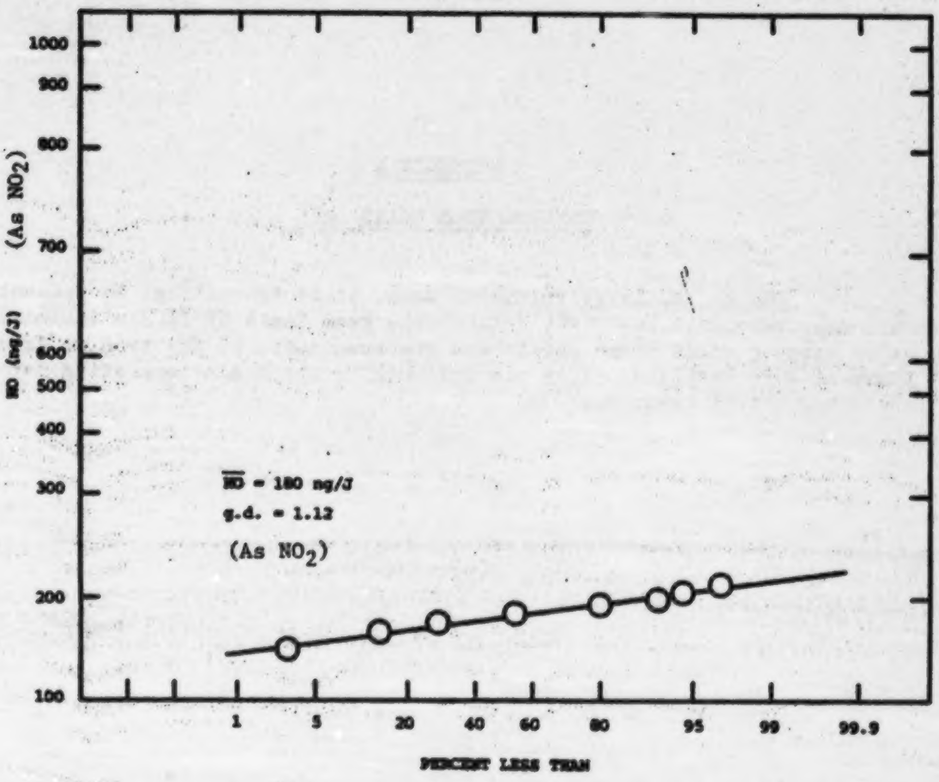


Figure F-III-18. Log probability curve of NO emissions
Conesville Unit 5, Test No. 2
May 5 - June 9, 1981

# PART G

# APPENDIXES

## APPENDIX A

## CONTROL ROOM BOARD DATA

Due to the large volume of data, it is impractical to present all such data here. Instead, the data sheets from Tests 69-71 are included here as an example since these sheets are representative of the type of data, and items of data recorded. They are followed by the boiler operating data from the Level 1 test (test No. 72).

| | | Units | Log Code | | | | |
|---|---|---|---|---|---|---|---|
| Test Number | | | | 69 | 70 | 71 | |
| Date 1980 | | M-D-Y | | 4-4-80 | 4-4-80 | 4-4-80 | |
| Time | | Military 24 hr | | 05:00 | 05:58 | 06:24 | |
| Purpose | | | | NEW O2 CAL | LOW AIR | MED AIR | |

SUMMARY

| | | Units | Log Code | | | | |
|---|---|---|---|---|---|---|---|
| Excess Air | | | | NORM | LOW | MED | |
| Firing Pattern | | | | C OFF E LOW | C OFF E LOW | C OFF E LOW | |
| Burner Tilt | | Deg. Up | B5316 | 0 | 0 | 0 | |
| O.F. Air Tilt | | Deg. Up | Local | -10 | -10 | -10 | |
| O.F. Air Dampers Percent Open | FF | % | Local | 75 | 75 | 75 | |
| | GG | % | Local | 75 | 75 | 75 | |
| Main Steam Flow | | KP/H | Board | 2360 | 2360 | 2360 | |
| Super Heat Temperature | A | °F | H5001 | 1000 | 996 | 984 | |
| | B | °F | H5002 | 999 | 996 | 983 | |
| Throttle Pressure | | Psig | T5139 | 2389 | 2396 | 2389 | |
| Generator Gross Load | | MW | T5321 | 327 | 328 | 325 | |

FLOW RATES

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| COAL FEEDS | | Total | % MCR (MCR = 500 KP/H) | B5341 | 60 | 60 | 60 | |
| | | A | KP/H | B5194 | 73.6 | 71.4 | 71.8 | |
| | | B | KP/H | B5197 | 76.0 | 75.1 | 75.2 | |
| | | C | KP/H | B5200 | OFF | 0.00 | 0.00 | |
| | | D | KP/H | B5203 | 77.6 | 75.99 | 75.96 | |
| | | E | KP/H | B5206 | 48.8 | 49.0 | 49.0 | |
| AIR | Secondary air to windbox | Total | % MCR (MCR = 3750 KP/HR) | Board | 71 | 58 | 64 | |
| | | Right | % MCR | B5185 | 53.1 | 38.3 | 46.7 | |
| | | Left | % MCR | B5184 | 56.9 | 44.6 | 52.1 | |
| | Primary air to Pulverizers (each mill in service uses ~4% of the total) | A | % MCR | B5187 | 79.4 | 79.8 | 79.8 | |
| | | B | % MCR | B5188 | 80.3 | 80.7 | 79.8 | |
| | | C | % MCR | B5189 | 0.00 | 7.5 | 7.6 | |
| | | D | % MCR | B5190 | 79.8 | 79.9 | 79.7 | |
| | | E | % MCR | B5191 | 80.4 | 80.3 | 80.1 | |
| Feedwater (MCR = 3500) | | | KP/H | F5181 | 2422 | 2443 | 2446 | |
| Main Steam (Turb 1st stg prs is better) | | | KP/H | Board | 2360 | 2360 | 2360 | |
| Reheat Steam | | | KP/H | Data point not available. May be found by heat balance. | | | | |
| Condensate (MCR = 2500) | | | KP/H | C5180 | 2042 | 2073 | 2066 | |
| Super Heat Spray | | | KP/H | F5179 | 190.1 | 168 | 163 | |
| Reheat Spray | | | KP/H | F5178 | BAD | BAD | BAD | |

**CONESVILLE #5** **CONTROL ROOM BOARD DATA (Pg 2 of 4)**

|  |  | Units | Log Code |  |  |  |  |
|---|---|---|---|---|---|---|---|
| Test Number |  |  |  | 69 | 70 | 71 |  |
| Date | 1980 | M-D-Y |  | 4.4.80 | 4.4.80 | 4.4.80 |  |
| Time |  | Military 24 hr |  | 05:02 | 06:00 | 06:27 |  |

DAMPERS (Windbox)

|  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|
| Fuel Air | A | % Open | Board | 97 | 96 | 96 |  |
|  | B | % Open | Board | 99 | 100 | 99 |  |
|  | C | % Open | Board | 0 | 0 | 0 |  |
|  | D | % Open | Board | 97 | 97 | 97 |  |
|  | E | % Open | Board | 40 | 40 | 40 |  |
| Auxiliary Air | AA | % Open | Board | ↑ | ↑ | ↑ |  |
|  | AB | % Open | Board |  |  |  |  |
|  | BC | % Open | Board | 12 | 12 | 12 |  |
|  | CD | % Open | Board |  |  |  |  |
|  | DE | % Open | Board |  |  |  |  |
|  | EE | % Open | Board | ↓ | ↓ | ↓ |  |
| Oil Heater Air | AB | % Open | Board | Not Available |  |  |  |
| Over Fire Air | FF | % Open | Board | 75 | 75 | 75 |  |
|  | GG | % Open | Board | 75 | 75 | 75 |  |

PRESSURES

|  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|
| Throttle |  | PSIG | T5139 | 2393 | 2394 | 2386 |  |
| Turbine First Stage |  | PSIG | T5132 | 1349 | 1351 | 1347 |  |
| Cold Reheat (Steam In) |  | PSIG | H5127 | 469 | 474 | 468 |  |
| Hot Reheat (Steam Out) |  | PSIG | H5126 | 428 | 433 | 427 |  |
| Primary Air | P.A. Fan out (= A. H. In) | In $H_2O$ | B5126 | 37.1 | 37.0 | 36.9 |  |
|  | Air Heater Out | In $H_2O$ | B5127 | 35.3 | 35.6 | 35.5 |  |
| Forced Draft Fan Outlet |  | In $H_2O$ | B5147 | 12.0 | 5.9 | 9.6 |  |
| Secondary Air at Air Heater | In | In $H_2O$ | B5157 | 9.4 | 4.0 | 7.2 |  |
|  | Out | In $H_2O$ | B5127 | 5.7 | 2.2 | 4.3 |  |
| Windbox |  | In $H_2O$ | B5149 | 4.3 | 1.0 | 2.8 |  |
| Furnace Gas (Wide Range) |  | In $H_2O$ | B5144 | -1.6 | -2.0 | -1.7 |  |
| Flue Gas | Reheater Outlet | In $H_2O$ | B5151 | -0.9 | -0.8 | -0.3 |  |
|  | Superheater Outlet | In $H_2O$ | B5150 | -2.3 | -1.7 | -1.7 |  |
|  | Economizer Inlet | In $H_2O$ |  | Not Available |  |  |  |
| Gas at Air Htr | Flue Gas In | In $H_2O$ | B5159 | -5.9 | -4.8 | -5.4 |  |
|  | Flue Gas Out | In $H_2O$ | B5152 | -9.2 | -6.6 | -7.8 |  |
| Flue Gas | Precipitator Outlet | In $H_2O$ | B5153 | -10.5 | -7.7 | -9.2 |  |
|  | Scrubber Inlet | In $H_2O$ | B5155 | BAD | BAD | BAD |  |
|  | Scrubber Outlet | In $H_2O$ | B5156 | -6.4 | -6.9 | -6.7 |  |
| Atmospheric Barometric |  | PSIA | P5306 | 14.23 | 14.24 | 14.24 |  |

**CONESVILLE #5** **CONTROL ROOM BOARD DATA (Pg 3 of 4)**

| | | | Units | Log Code | | | | |
|---|---|---|---|---|---|---|---|---|
| Test Number | | | | | 69 | 70 | 71 | |
| Date | | 1980 | M-D-Y | | 4-4-80 | 4-4-80 | 4-4-80 | |
| Time | | | Military 24 hr | | 05:04 | 06:08 | 06:38 | |

**TEMPERATURES**

| | | | Units | Log Code | | | | |
|---|---|---|---|---|---|---|---|---|
| Ambient Air | | | °F | P5307 | 50 | 48 | 47 | |
| Ambient Air Dew Point | | | °F | P5305 | 46 | 47 | 44 | |
| Flue Gas out of Economizer | | | °F | B5008 | 719 | 654 | 688 | |
| AIR HEATER | Furnace Flue Gas | In | °F | B5101 | 652 | 627 | 640 | |
| | | Out | °F | B5098 | 311 | 311 | 308 | |
| | Primary Air | In | °F | B5102 | 99 | 101 | 99 | |
| | | Out | °F | B5100 | 611 | 583 | 591 | |
| | Secondary Air | In | °F | B5906 | 107 | 119 | 112 | |
| | | Out | °F | B5006 | 551 | 546 | 543 | |
| COAL MILL OUTLETS | | A | °F | B5118 | 148 | 148 | 148 | |
| | | B | °F | B5119 | 158 | 158 | 158 | |
| | | C | °F | B5120 | 74 | 89 | 90 | |
| | | D | °F | B5121 | 161 | 160 | 161 | |
| | | E | °F | B5122 | 142 | 142 | 143 | |
| Feed Water to Economizer | | | °F | F5008 | 459 | 460 | 459 | |
| SPRAYS | Super Heat | | °F | Same as Feedwater to Economizer | | | | |
| | Reheat | | °F | F5532 | 250 | 250 | 250 | |
| Superheater Desuperheat | A | In | °F | Board | 790 | 770 | 790 | |
| | | Out | °F | Board | 730 | 710 | 660 | |
| | B | In | °F | Board | 780 | 750 | 760 | |
| | | Out | °F | Board | 740 | 730 | 730 | |
| Cold Reheat | | In | °F | H5507 | 621 | 625 | 625 | |
| Reheater Desuperheat | A | In | °F | Board | 550 | 500 | 530 | |
| | | Out | °F | Board | 540 | 515 | 570 | |
| | B | In | °F | Board | 650 | 550 | 640 | |
| | | Out | °F | Board | 570 | 575 | 570 | |
| Superheater Outlet | A | | °F | H5001 | 998 | 994 | 991 | |
| | B | | °F | H5002 | 998 | 995 | 989 | |
| Reheater Outlet | A | | °F | H5003 | 1005 | 992 | 999 | |
| | B | | °F | H5004 | 993 | 998 | 983 | |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |

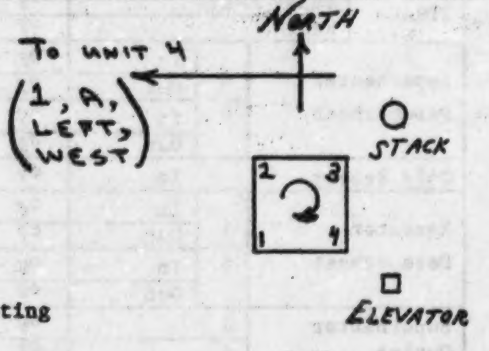
| | Units | Log Code | | | | |
|---|---|---|---|---|---|---|
| Test Number | | | 69 | 70 | 71 | |
| Date 1980 | M-D-Y | | 4.4.80 | 4.4.80 | 4.4.80 | |
| Time | Military 24 hr | | 05:06 | 05:58 | 06:38 | |

**EMISSIONS**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| OXYGEN | West 1 | % | B5301 | 4.6 | 1.2 | 3.0 | |
| | Center 2 | % | B5302 | 4.9 | 1.8 | 3.5 | |
| | East 3 | % | B5303 | 4.7 | 1.4 | 3.3 | |
| | Average | % | Board | 4.85 | 1.4 | 3.4 | |
| Combustibles (0-10%) | | % | Board | 0 | 0 | 0 | |
| $NO_x$ | | | P5303 | – | – | – | |
| Opacity* | Electronic | % | P5304 | 85.63 | 62.3 | 78.0 | |
| | Observer ____ | % | | | | | |

**MISCELLANEOUS**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Drum Pressure (on CRT) | | PSIG | H5129 | | 2522 | 2520 | |
| Superheater Outlet Pressure | | PSIG | H5130 | | 2421 | 2518 | |
| Soot Blower Air Flow | | %MCR | Board | 0 | 0 | 0 | |
| Scrubber (on or off) | | | | ON | ON | ON | |
| REHEAT SPRAY VALVES | A | % OPEN | BOARD | | | 0 | |
| | B | % OPEN | BOARD | | | 0 | |



Boiler Geometry
Nomenclature
(1 = A = Left = West)

**ABBREVIATIONS**

SH: Super Heater
AH: Air Heater
RH: Re Heater
MCR: Maximum Continuous Rating

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*The plant's transmissometer readings were consistently higher than the opacity readings made by the certified observer, and should probably be discounted. However, during these early morning tests (still too dark to see the stack), observer readings were not made.

## CONTROL ROOM BOARD DATA

DATE: 9/10/80. LEVEL 1 TEST. EXXON TEST #72

| TIME: | | 1600 | 1730 | 1900 | 2030 | 2200 | AVG |
|---|---|---|---|---|---|---|---|
| Hot Reheat (LH) | oF | 1000 | 990 | 1000 | 1020 | 1010 | |
| (RH) | oF | 1000 | 1000 | 1000 | 1020 | 1010 | |
| Throttle Steam | oF | 960 | 960 | 960 | 980 | 1010 | |
| Load (Gross) | MW | 408 | | 408 | 408 | 402 | 408 |
| Load (Gross) Demand | MW | 413 | 413 | 411 | 410 | 412 | |
| FW Flow | $10^6$ lb/hr | 2.62 | 2.62 | 2.60 | 2.55 | 2.62 | |
| FW Pressure | PSIG | 2870 | 2870 | 2870 | 2840 | 2840 | |
| Drum Level | in. above center | -5.5 | -5.0 | -5.5 | -5.5 | -5.5 | |
| SH Outlet Pres. | PSIG | 2400 | 2400 | 2400 | 2400 | 2400 | |
| Steam Flow | $10^6$ lb/hr | 2.90 | 2.90 | 2.90 | 2.90 | 2.91 | |
| Total Air Flow | % | 90 | 92 | 90 | 91 | 92 | |
| A Reheat Outlet | oF | 1050 | 1032 | 1026 | 1032 | | |
| A Reheat Desup Out | oF | 658 | 578 | 566 | 560 | System Load Change<br>End of Test. | |
| B Reheat Outlet | oF | 1025 | 1005 | 1000 | 1019 | | |
| B Reheat Desup Out | oF | 650 | 580 | 540 | 555 | | |

## CONTROL ROOM BOARD DATA
## (CONTINUED)

DATE: 9/10/80

| TIME: | | 1600 | 1730 | 1900 | 2030 | 2200 |
|---|---|---|---|---|---|---|
| SH Spray Flow | $10^5$ lb/hr | 2.60 | 2.40 | 2.62 | 2.94 | |
| RH Spray | GPM | 0 | 0 | 0 | 0 | |
| A Final SH Outlet T | °F | 1000 | 1007 | 990 | 1000 | |
| A Interstage SH Outlet T | °F | 680 | 680 | 670 | 675 | |
| B Final SH Outlet T | °F | 1000 | 1000 | 1010 | 1012 | |
| B Interstage SH Outlet T | °F | 710 | 710 | 730 | 715 | |
| AH Air Inlet T | °F | 100 | 92 | 92 | 90 | |
| AH Gas Outlet T | °F | 315 | 308 | 308 | 308 | |
| SH Desup. A Inlet T | °F | 780 | 780 | 780 | 780 | |
| SH Desup. A Outlet T | °F | 730 | 730 | 720 | 720 | |
| SH Desup. B Inlet T | °F | 760 | 760 | 770 | 770 | |
| SH Desup. B Outlet T | °F | 740 | 740 | 750 | 740 | |
| RH Desup. A Inlet T | °F | 655 | 580 | 575 | 560 | |
| RH Desup. A Outlet T | °F | 645 | 560 | 555 | 540 | |
| RH Desup. B Inlet T | °F | 680 | 680 | 680 | 680 | |
| RH Desup. B Outlet T | °F | 600 | 605 | 610 | 600 | |
| Drum Pressure | PSIG | 2550 | 2550 | 2550 | 2550 | |
| Drum Level | in. above center | -1 | -2 | -2 | -3 | |
| A Reheat Spray Valve | % | 4 | 4 | 4 | 10 | |
| B Reheat Spray Valve | % | 0 | 3 | 3 | 10 | |
| A SH Spray Valve | % | 48 | 41 | 58 | 60 | |
| B SH Spray Valve | % | 21 | 21 | 21 | 24 | |
| Avg Burner Tilt | Deg. up | 0 | -9 | -14 | -14 | |
| BFP Discharge Pres. | PSI | 2850 | 2920 | 2920 | 2830 | |
| BFP Discharge Flow | $10^6$ lb/hr | 267 | 2170 | 2166 | 2166 | |

## CONTROL ROOM BOARD DATA
## (CONTINUED)

DATE: 9/10/80

| TIME: | | 1600 | 1730 | 1900 | 2030 | 2200 |
|---|---|---|---|---|---|---|
| PA Fan disch pres. | in $H_2O$ | 36 | 36 | 36 | 36 | |
| PA pres. from AH | in $H_2O$ | 36 | 36 | 36 | 36 | |
| PA/furn diff. pres | in $H_2O$ | 34 | 34 | 34 | 34 | |
| FD Fan disch pres. | in $H_2O$ | 16 | 17 | 17 | 17 | |
| Sec. Air to AH pres | in $H_2O$ | 12 | 13 | 13 | 13 | |
| Sec. Air from AH | in $H_2O$ | 8 | 8 | 8 | 9 | |
| Igniter Windbox pres | in $H_2O$ | 1 | 1 | 1.2 | 1.2 | |
| Windbox pres | in $H_2O$ | 5 | 5 | 5.4 | 5.6 | |
| Furnace Draft | in $H_2O$ | −0.5 | −0.5 | −0.5 | −0.2 | |
| Flue gas from RH | in $H_2O$ | −1.0 | −1.0 | −0.8 | −0.8 | |
| Flue gas from SH | in $H_2O$ | −3.0 | −2.8 | −2.4 | −2.6 | |
| ID Fan A Speed | RPM | 690 | 710 | 680 | 700 | |
| ID Fan B Speed | RPM | 690 | 710 | 680 | 700 | |
| Aux. Air Damper % | | 26 | 30 | 26 | 26 | |
| Mill A Fuel Air Damper (Bottom) | % | 0 | 0 | 0 | 0 | |
| Mill B Fuel Air Damper | % | 100 | 100 | 100 | 100 | |
| Mill C Fuel Air Damper | % | 98 | 98 | 98 | 98 | |
| Mill D Fuel Air Damper | % | 96 | 96 | 96 | 96 | |
| Mill E Fuel Air Damper (Top) | % | 97 | 97 | 97 | 97 | |
| % $O_2$ | | 4.0 | 4.0 | 4.0 | 4.0 | |
| Total air flow % | $10^3$ lb/hr (Chart) | 92 | 92 | 92 | 91 | |
| Total coal flow* | $10^3$ lb/hr | 375 | 380 | 380 | 380 | |
| % $O_2$ | | 3.8 | 3.8 | 3.6 | 3.6 | |
| Flue Gas to AH | in $H_2O$ | −7.5 | −8.0 | −7.5 | −7.5 | |
| Flue Gas from AH | in $H_2O$ | −12 | −13 | −12.5 | −12.5 | |
| Flue Gas from ESP | in $H_2O$ | −14 | −14.5 | −14 | −14 | |
| Flue Gas to Scrubber | in $H_2O$ | 6.0 | 4.5 | 5.0 | 5.0 | |
| Flue Gas from Scrubber | in $H_2O$ | 2.5 | 5.0 | 2.4 | 2.6 | |

* NOTE: Total coal flow gauge reads 10% higher than the sum of the individual gauge readings.

# CONTROL ROOM BOARD DATA
## (CONTINUED)

DATE: 9/10/80

| TIME: | | 1600 | 1730 | 1900 | 2030 | 2200 | AVG |
|---|---|---|---|---|---|---|---|
| AH gas outlet T | °F | 306 | 305 | 308 | 308 | | |
| Fan room T | °F | 82 | 81 | 78 | 76 | | |
| FD Fan A | AMPS | 225 | 225 | 225 | 225 | | |
| FD Fan B | AMPS | 245 | 245 | 245 | 245 | | |
| ID Fan A | AMPS | 700 | 690 | 680 | 680 | | |
| ID Fan B | AMPS | 680 | 680 | 650 | 660 | | |
| PA Fan A | AMPS | 160 | 160 | 160 | 160 | | |
| PA Fan B | AMPS | 160 | 160 | 160 | 160 | | |
| Feeder A speed | % | 0 | | | | | |
| Mill A/Furn ΔP | in $H_2O$ | 0 | | | | | |
| Mill A Bowl ΔP | in $H_2O$ | 0 | | | | | |
| Mill A Temp | °F | 75 | | | | | |
| Mill A Coal Feeder Rate | $10^3$ ppH | 0 | | | | | |
| Mill A | AMPS | 0 | | | | | |
| Feeder B speed | % | 78 | 78 | 80 | 80 | | |
| Mill B/Furn ΔP | in $H_2O$ | 23.5 | 23.5 | 23.5 | 24 | | |
| Mill B Bowl ΔP | in $H_2O$ | 6.0 | 6.2 | 6.2 | 6.4 | | |
| Mill B Temp | °F | 150 | 150 | 152 | 151 | | |
| Mill B Coal Feeder Rate | $10^3$ ppH | 88 | 90 | 91 | 90 | | 90 |
| Mill B | AMPS | 76 | 76 | 77 | 78 | | |
| Feeder C speed | % | 78 | 80 | 80 | 81 | | |
| Mill C/Furn ΔP | in $H_2O$ | 24.5 | 25.0 | 24 | 35 | | |
| Mill C Bowl ΔP | in $H_2O$ | 6.5 | 6.6 | 6.5 | 6.6 | | |
| Mill C Temp | °F | 160 | 160 | 160 | 162 | | |
| Mill C Coal Feeder Rate | $10^3$ ppH | 87 | 87 | 87 | 89 | | 88 |
| Mill C | AMPS | 12 | 12 | 71 | 71 | | |
| Feeder D Speed | % | 79 | 80 | 80 | 81 | | |
| Mill D/Furn ΔP | in $H_2O$ | 25 | 25 | 25 | 25 | | |
| Mill D. Bowl ΔP | in $H_2O$ | 6.5 | 6.5 | 6.6 | 6.6 | | |
| Mill D Temp | °F | 145 | 145 | 145 | 145 | | |
| Mill D Coal Feeder Rate | $10^3$ ppH | 87 | 87 | 88 | 90 | | 88 |
| Mill D | AMPS | 68 | 70 | 65 | 70 | | |

## CONTROL ROOM BOARD DATA
## (CONTINUED)

DATE: 9/10/80

| TIME: | | 1600 | 1730 | 1900 | 2030 | 2200 | AVG |
|---|---|---|---|---|---|---|---|
| Feeder E Speed | % | 77 | 78 | 78 | 80 | | |
| Mill E Furn ΔP | in $H_2O$ | 25 | 25 | 25 | 225 | | |
| Mill E Bowl ΔP | in $H_2O$ | 7 | 7 | 7 | 7 | | |
| Mill E Temp | °F | 150 | 150 | 150 | 151 | | |
| Mill E Coal Feeder Rate | $10^3$ ppH | 81 | 81 | 81 | 84 | | 82 |
| Mill E | AMPS | 80 | 80 | 80 | 82 | | |
| Condensate Flow | $10^6$ ppH | 2.10 | 2.10 | 2.10 | 2.10 | | |
| Condenser Vacuum | in Hg | 1.0 | 1.0 | 1.0 | 1.0 | | |
| Barometer | | 29.4 | | | | | |
| T wet bulb | | | | | | | |
| HP Heater Extraction Pres | psig | 595 | 600 | 600 | 600 | | |
| HP Heater Extraction Temp | °F | 643 | 641 | 639 | 650 | | |
| HP Heater Drain Temp | °F | 423 | 425 | 425 | 425 | | |
| HP Heater FW Inlet Temp | °F | 409 | 410 | 410 | 410 | | |
| HP Heater FW Outlet Temp | °F | 491 | 492 | 492 | 493 | | |
| OFA TILT<br>(deg up) | c b<br>d a<br>Front | a: -15, b: -10, c: -10, d: -10. | | | | | |
| Aux Air Dampers AA | % Open | | 0 | 0 | 0 | | |
| $AB_{1,3}$ | | | 50 | 20 | 20 | | |
| $AB_2$ (Oil Air) | | | 50 | 50 | 50 | | |
| BC | | | 50 | 40 | 30 | | |
| CD | | | 40 | 20 | 40 | | |
| DE | | | 40 | 40 | 40 | | |
| EE | | | 40 | 40 | 40 | | |
| FF (OFA) | | | 60 | 60 | 70 | | |
| GG (OFA) | | | 70 | 70 | 70 | | |

## APPENDIX B

## COAL AND ASH ANALYSIS

(ADDITIONAL FUEL DATA MAY BE FOUND IN APPENDIX G.)

## AS-FIRED COAL BURNED ON 3-24-80
## (TEST NO. 64, INCLUDES GAS TAP TEST)

C&SOE CONESVILLE UNIT NO. 5
Date submitted: 6/11/80
Date reported: 8/11/80

| BASIS: | AS ANALYZED | DRY | DAF | DMMF | AS RECEIVED |
|---|---|---|---|---|---|
| Moisture | 5.78 | | | | 6.70 |
| Ash (Min. Matter) | 12.70 | 13.48 | | (17.62) | 12.58 |
| $SO_3$ Free Ash | 12.37 | 13.13 | | | 12.25 |
| Carb-Hyd Residue | 12.28 | 13.03 | | | 12.16 |
| Volatile Matter | 34.60 | 36.72 | 42.44 | 40.67 | 34.26 |
| Fixed Carbon | 46.92 | 49.80 | 57.56 | 59.33 | 46.46 |
| Btu (Mott-Spooner) | 11562. | 12271. | 14183. | 14674.<br>(14735.) | 11449. |
| Carbon | 63.99 | 67.92 | 78.50 | 82.19 | 63.37 |
| Hydrogen ($xH_2O$) | 4.45 | 4.73 | 5.46 | 5.64 | 4.41 |
| Nitrogen | 1.10 | 1.17 | 1.35 | 1.42 | 1.09 |
| Oxygen (Diff-$xH_2O$,Cl) | 7.72 | 8.19 | 9.47 | 9.95 | 7.64 |
| Chlorine | 0.06 | 0.06 | 0.07 | 0.08 | 0.06 |
| Sulfur, Total (LECO) | 4.26 | 4.52 | 5.23 | | 4.22 |
| Sulfur, Pyritic | 3.33 | 3.53 | | | 3.30 |
| Sulfur, Sulfate | 0.31 | 0.33 | | | 0.31 |
| Sulfur, Org: DF/ES | 0.62 | 0.66 | 0.76 | 0.80 | 0.61 |
| Carbon Dioxide | 0.72 | 0.76 | 0.88 | 0.93 | 0.71 |
| Fe (HCl Soluble) | 0.60 | 0.64 | | | 0.59 |
| Fe ($HNO_3$ Soluble) | 2.90 | 3.08 | | | 2.87 |
| Ash Alk. (As % $Na_2O$) | 0.18 | 0.19 | | | 0.17 |

| ASH FUSION ANALYSIS: | Reducing Atmosphere | | | | Oxidizing Atmosphere | | | |
|---|---|---|---|---|---|---|---|---|
| | ID | H=W | H=W/2 | Fluid | ID | H=W | H=W/2 | Fluid |
| Temp (°F) | 1940 | 1960 | 2000 | 2045 | 2460 | 2500 | 2510 | 2525 |

**ELEMENTAL ANALYSIS OF DRY ASH:**

| wt% | $P_2O_5$ | $SiO_2$ | $Fe_2O_3$ | $Al_2O_3$ | $TiO_2$ | CaO | MgO | $SO_3$ | $K_2O$ | $Na_2O$ | TOTAL | DIFF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (w/$SO_3$ | 0.28 | 40.64 | 29.30 | 19.56 | 1.01 | 2.08 | 0.86 | 2.60 | 1.66 | 0.29 | 98.28 | 1.72 |
| (w/o $SO_3$) | 0.29 | 42.47 | 30.62 | 20.44 | 1.06 | 2.17 | 0.90 | - | 1.73 | 0.30 | | |

| | |
|---|---|
| GRINDABILITY (HGI): 55.2 | HGI MOISTURE: 6.06 |

| | | | |
|---|---|---|---|
| QUALITY FACTORS: | B/A Ratio: 0.56<br>Dol. Ratio: 0.09<br>Si. Val.: 0.56 | Slag Index: 2.53<br>Fe2O3/CaO: 14.09<br>CVT: 2200 | Foul Index: 0.16<br>Si/Al: 2.08 |

## AS-FIRED COAL BURNED ON 3-25-80
## (TEST NO. 64 AND 65, INCLUDES GAS TAP TEST)

CONESVILLE UNIT NO. 5
Date submitted: 06/11/80
Date reported: 08/11/80

| BASIS | AS ANALYZED | DRY | DAF | DMMF | AS RECEIVED |
|---|---|---|---|---|---|
| Moisture | 5.93 | 14.11 | | | 7.72 |
| Ash (min. matter) | 13.27 | 14.11 | | (18.70) | 13.02 |
| $SO_3$ Free Ash | 12.92 | 13.74 | | | 12.68 |
| Carb-hyd Residue | 12.79 | 13.60 | | | 12.55 |
| Volatile Matter | 36.53 | 38.83 | 45.41 | 44.06 | 35.83 |
| Fixed Carbon | 44.27 | 47.06 | 54.79 | 55.94 | 43.43 |
| Btu (Mott-Spooner) | 11281. | 11993. | 13962. | 14529.<br>(14647.) | 11067. |
| Carbon | 62.58 | 66.52 | 72.45 | 81.64 | 61.39 |
| Hydrogen ($xH_2O$) | 4.40 | 4.67 | 5.44 | 5.65 | 4.31 |
| Oxygen (Diff-$xH_2O$, Cl) | 8.20 | 8.72 | 10.15 | 10.22 | 8.05 |
| Chlorine | 0.12 | 0.13 | 0.15 | 0.16 | 0.12 |
| Sulfur, Total (LECO) | 4.48 | 4.76 | 5.54 | | 4.39 |
| Sulfur, Pyritic | 3.21 | 3.41 | | | 3.15 |
| Sulfur, ORG: DF/ES | 0.77 | 0.82 | 0.95 | 1.01 | 0.76 |
| Sulfur, Sulfate | 0.50 | 0.53 | | | 0.49 |
| Carbon Dioxide | 0.52 | 0.55 | 0.64 | 0.68 | 0.51 |
| Fe (HCl Soluble) | 0.85 | 0.90 | | | 0.83 |
| Fe ($HNO_3$ Soluble) | 2.80 | 2.98 | | | 2.75 |
| Ash Alk. (as $Na_2O$) | 0.17 | 0.18 | | | 0.17 |

| ASH FUSION ANALYSIS: | Reducing Atmosphere | | | | Oxidizing Atmosphere | | | |
|---|---|---|---|---|---|---|---|---|
| | ID | H=W | H=W/2 | Fluid | ID | H=W | H=W/2 | Fluid |
| Temp. (°F) | 1990 | 2020 | 2035 | 2050 | 2450 | 2505 | 2520 | 2525 |

**ELEMENTAL ANALYSIS OF DRY ASH:**

| wt% | $P_2O_5$ | $SiO_2$ | $Fe_2O_3$ | $Al_2O_3$ | $TiO_2$ | CaO | MgO | $SO_3$ | $K_2O$ | $Na_2O$ | TOTAL | DIFF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (w/$SO_3$) | 0.27 | 29.94 | 29.50 | 20.18 | 0.94 | 1.82 | 0.81 | 2.63 | 1.63 | 0.23 | 97.95 | 2.05 |
| (w/o $SO_3$) | 0.28 | 41.90 | 30.95 | 21.17 | 0.99 | 1.91 | 0.85 | - | 1.71 | 0.24 | | |

| GRINDABILITY (HGI): 58.9 | HGI MOISTURE: 6.48 |
|---|---|

| QUALITY FACTORS: | B/A Ratio: 0.56<br>Dol. Ratio: 0.08<br>Si. Val.: 0.55 | Slag Index: 2.65<br>$Fe_2O_3$/CaO: 16.21<br>CVT: 2235 | Foul Index: 0.13<br>Si/Al: 1.98 |
|---|---|---|---|

## AS-FIRED COAL BURNED ON 3-27-80
## (TAKEN AFTER TEST NOS. 66-68)

**CONESVILLE NO. 5**
**Date submitted: 6/11/80**
**Date reported: 7/16/80**

| BASIS | AS ANALYZED | DRY | DAF | DMMF | AS RECEIVED |
|---|---|---|---|---|---|
| Moisture | 5.94 | | | | 6.86 |
| Ash (min. matter) | 12.45 | 13.24 | | (17.05) | 12.33 |
| $SO_3$ Free Ash | 12.12 | 12.88 | | | 12.00 |
| Carb-Hyd Residue | 12.03 | 12.79 | | | 11.91 |
| Volatile Matter | 36.26 | 38.55 | 55.57 | 56.84 | 44.91 |
| Fixed Carbon | 45.35 | 48.21 | 55.57 | 56.84 | 44.91 |
| Btu (Mott-Spooner) | 11460. | 12184. | 14043. | 14456.<br>(14503.) | 11348. |
| Carbon | 63.47 | 67.48 | 77.77 | 81.26 | 62.85 |
| Hydrogen ($xH_2O$) | 4.46 | 4.74 | 5.46 | 5.62 | 4.41 |
| Nitrogen | 1.13 | 1.20 | 1.38 | 1.45 | 1.12 |
| Oxygen (Diff-$xH_2O$, Cl) | 8.39 | 8.92 | 10.29 | 11.09 | 8.31 |
| Chlorine | 0.11 | 0.12 | 0.13 | 0.14 | 0.11 |
| Sulfur, Total (LECO) | 4.16 | 4.42 | 5.10 | | 4.12 |
| Sulfur, Pyritic | 3.33 | 3.54 | | | 3.30 |
| Sulfur, Sulfate | 0.37 | 0.39 | | | 0.37 |
| Sulfur, ORG: DF/ES | 0.46 | 0.49 | 0.56 | 0.59 | 0.46 |
| Carbon Dioxide | 0.26 | 0.28 | 0.32 | 0.33 | 0.26 |
| FE (HCl Soluble) | 0.73 | 0.78 | | | 0.72 |
| FE ($HNO_3$ Soluble) | 2.90 | 3.08 | | | 2.87 |
| Ash Alk. (as % $Na_2O$) | 0.17 | 0.18 | | | 0.17 |

| ASH FUSION ANALYSIS: | Reducing Atmosphere | | | | Oxidizing Atmosphere | | | |
|---|---|---|---|---|---|---|---|---|
| | ID | H=W | H=W/2 | Fluid | ID | H=W | H=W/2 | Fluid |
| Temp. (°F) | 1985 | 2015 | 2035 | 2050 | 2450 | 2510 | 2515 | 2525 |

**ELEMENTAL ANALYSIS OF DRY ASH:**

| wt% | $P_2O_5$ | $SiO_2$ | $Fe_2O_3$ | $Al_2O_3$ | $TiO_2$ | CaO | MgO | $SO_3$ | $K_2O$ | $Na_2O$ | TOTAL | DIFF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ($wSO_3$) | 0.31 | 40.57 | 29.23 | 20.14 | 0.89 | 1.81 | 0.75 | 2.68 | 1.67 | 0.29 | 98.34 | 1.66 |
| ($xSO_3$) | 0.32 | 42.41 | 30.56 | 21.05 | 0.93 | 1.89 | 0.78 | - | 1.75 | 0.30 | | |

| GRINDABILITY (HGI): 52.9 | HGI MOISTURE: 6.40 |
|---|---|

| QUALITY FACTORS: | | | |
|---|---|---|---|
| | B/A Ratio: 0.55 | Slag Index: 2.42 | Foul Index: 0.16 |
| | Dol. Ratio: 0.08 | $Fe_2O_3$/CaO: 16.15 | Si/Al: 2.01 |
| | Si. Val.: 0.56 | CVT: 2235 | |

## AS-FIRED COAL BURNED ON 4-10-80
## (1ST 30-HOUR CORROSION PROBE TEST)

C&SOE CONESVILLE UNIT NO. 5
Date submitted: 6/11/80
Date reported: 7/16/80

| BASIS | AS ANALYZED | DRY | DAF | DMMF | AS RECEIVED |
|---|---|---|---|---|---|
| Moisture | 6.34 | | | | 9.12 |
| Ash (Min. Matter) | 13.68 | 14.61 | | (18.41) | 13.27 |
| $SO_3$ Free Ash | 13.27 | 14.16 | | | 12.87 |
| Carb-Hyd Residue | 12.89 | 13.76 | | | 12.51 |
| Volatile Matter | 33.58 | 36.14 | 42.32 | 41.30 | 32.85 |
| Fixed Carbon | 46.13 | 49.25 | 57.68 | 58.70 | 44.76 |
| Btu (Mott-Spooner) | 11060. | 11809. | 13829. | 14314.<br>(14483.) | 10732. |
| Carbon | 62.11 | 66.31 | 77.66 | 81.18 | 60.27 |
| Hydrogen ($xH_2O$) | 4.24 | 4.53 | 5.30 | 5.42 | 4.11 |
| Nitrogen | 1.12 | 1.20 | 1.40 | 1.47 | 1.09 |
| Oxygen (Diff-$xH_2O$, Cl) | 8.32 | 8.88 | 10.40 | 10.12 | 8.07 |
| Chlorine | 0.09 | 0.10 | 0.11 | 0.12 | 0.09 |
| Sulfur, Total (LECO) | 4.19 | 4.47 | 5.24 | | 4.07 |
| Sulfur, Pyritic | 2.28 | 2.43 | | | 2.21 |
| Sulfur, Sulfate | 0.52 | 0.56 | | | 0.50 |
| Sulfur, ORG: DF/ES | 1.39 | 1.48 | 1.74 | 1.82 | 1.35 |
| Carbon Dioxide | 0.28 | 0.30 | 0.35 | 0.37 | 0.27 |
| Fe (HCl Soluble) | 0.95 | 1.01 | | | 0.92 |
| Fe ($HNO_3$ Soluble) | 1.99 | 2.12 | | | 1.93 |
| Ash Alk. (as % $NA_2O$) | 0.18 | 0.20 | | | 0.18 |

| ASH FUSION ANALYSIS: | Reducing Atmosphere | | | | Oxidizing Atmosphere | | | |
|---|---|---|---|---|---|---|---|---|
| | ID | H=W | H=W/2 | Fluid | ID | H=W | H=W/2 | Fluid |
| Temp. (°F) | 1950 | 2000 | 2010 | 2030 | 2470 | 2490 | 2495 | 2500 |

**ELEMENTAL ANALYSIS OF DRY ASH:**

| wt% | $P_2O_5$ | $SiO_2$ | $Fe_2O_3$ | $Al_2O_3$ | $TiO_2$ | CaO | MgO | $SO_3$ | $K_2O$ | $Na_2O$ | TOTAL | DIFF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ($wSO_3$) | 0.37 | 41.01 | 28.40 | 19.66 | 1.00 | 1.96 | 0.79 | 3.03 | 1.67 | 0.24 | 98.13 | 1.87 |
| ($xSO_3$) | 0.39 | 43.12 | 29.86 | 20.67 | 1.50 | 2.06 | 0.83 | – | 1.96 | 0.25 | | |

| GRINDABILITY (HGI): 55.9 | HGI MOISTURE: 7.81 |
|---|---|

| QUALITY FACTORS: | | | | | | |
|---|---|---|---|---|---|---|
| | B/A Ratio: | 0.54 | Slag Index: | 2.40 | Foul Index: | 0.13 |
| | Dol. Ratio: | 0.08 | $Fe_2O_3$/CaO: | 14.49 | Si/Al: | 2.09 |
| | Si. Val.: | 0.57 | CVT: | 2210 | | |

## AS-FIRED COAL BURNED ON 9-10-80*
## (LEVEL 1 TEST NO. 72)

## C&SOE CONESVILLE NO. 5

| BASIS | AS ANALYZED | DRY | DAF | DMMF | AS RECEIVED |
|---|---|---|---|---|---|
| Moisture | 2.32 | | | | 7.56 |
| Ash | 14.37 | 14.71 | | 18.59 | |
| $SO_3$ Free Ash | 14.02 | 14.35 | | | |
| Carb-Hyd Residue | 14.15 | 14.48 | | | |
| Volatile Matter | 38.69 | 39.61 | 46.44 | 45.07 | |
| Fixed Carbon | 44.62 | 45.68 | 53.56 | 54.93 | |
| Btu | 11843. | 12124. | 42116. | 14699. | |
| Carbon | 64.49 | 66.02 | 77.41 | 80.95 | |
| Hydrogen | 4.54 | 4.64 | 5.45 | 5.57 | |
| Nitrogen | 1.37 | 1.40 | 1.64 | 1.72 | |
| Oxygen (Diff-$xH_2O$, Cl) | 7.60 | 7.78 | 9.12 | 8.94 | |
| Chorine | 0.09 | 0.09 | 0.11 | 0.12 | |
| Sulfur, Total (LECO) | 5.32 | 5.45 | 6.38 | | |
| Pyritic | 2.90 | 2.97 | | | |
| Sulfate | 0.17 | 0.18 | | | |
| Organic DF/ES | 2.24 | 2.29 | 2.69 | 2.82 | |
| Carbon Dioxide | 0.41 | 0.42 | 0.49 | 0.51 | |
| Undetermined | 7.60 | | | | |
| Fe (HCl Soluble) | 0.00 | 0.00 | | | |
| Fe ($HNO_3$ Soluble) | 2.57 | 2.63 | | | |
| Ash Alk. (as % $Na_2O$) | 0.19 | 0.20 | | | |

| ASH FUSION: | Reducing Atmosphere | | | | Oxidizing Atmosphere | | | |
|---|---|---|---|---|---|---|---|---|
| | ID | H-W | H-W/2 | Fluid | ID | H-W | H-W/2 | Fluid |
| Temp. (°F) | 1975 | 2015 | 2040 | 2070 | 2450 | 2500 | 2530 | 2575 |

ELEMENTAL ANALYSIS OF DRY ASH (WT%):

| wt % | $P_2O_5$ | $SiO_3$ | $Fe_2O_3$ | $Al_2O_3$ | $TiO_3$ | CaO | MgO | $SO_3$ | $K_2O$ | $NaO_2$ | TOTAL | DIFF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (w/$SO_3$) | 0.25 | 38.49 | 33.79 | 17.81 | 0.90 | 2.08 | 0.98 | 2.45 | 1.61 | 0.28 | 98.63 | 1.37 |
| (w/o$SO_3$) | 0.26 | 40.02 | 35.12 | 18.52 | 0.93 | 2.17 | 1.01 | | 1.67 | 0.30 | | |

| QUALITY FACTORS: | | | |
|---|---|---|---|
| | B/A Ratio: 0.68 | Slag Index: 3.69 | Foul Index: 0.19 |
| | Dol. Ratio: 0.09 | $Fe_2O_3$/CaO: 16.21 | Si/Al: 2.16 |
| | Si. Value: 0.51 | CVT: 2270.0 | |

| | |
|---|---|
| MOTT-SPOONER: | 14653. |
| HGI MOISTURE: | 2.63 |
| GRINDABILITY (HGI): | 54.00 |

*Sample is from Coal Belt Feed to Silos. Sampled prior to 9:00 a.m. 9/10/80.

## FLY ASH FROM ESP HOPPERS*
## (LEVEL 1 TEST NO. 72)

### CONESVILLE NO. 5 ASH

| | ANALYZED | DRY | DAF (DAY, ASH FREE) |
|---|---|---|---|
| Moisture | 0.23 | | |
| Ash | 98.84 | 99.06 | |
| $SO_3$ Free Ash | 98.71 | 98.93 | |
| Carb-Hyd Residue | 98.34 | 98.57 | |
| Carbon | 0.84 | 0.84 | 89.86 |
| Hydrogen | 0.10 | 0.10 | 10.22 |
| Carbon Dioxide | 0.09 | 0.09 | 9.42 |
| Ash Alk. (as % $Na_2O$) | 1.53 | 1.53 | |

| | | | |
|---|---|---|---|
| SOLUBLES IN HCR (% DRY) ASH: | Na = 0.12 | K = 5.46 | Ca = 0.99 |

ELEMENTAL ANALYSIS OF DRY ASH (WT%):

| wt% | $P_2O_5$ | $SiO_3$ | $Fe_2O_3$ | $Al_2O_3$ | $TiO_3$ | CaO | MgO | $SO_3$ | $K_2O$ | $NaO_2$ | TOTAL | DIFF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (w/$SO_3$) | 0.26 | 40.71 | 30.96 | 19.73 | 1.05 | 1.72 | 0.92 | 0.13 | 1.80 | 0.36 | 96.65 | 2.35 |
| (x$SO_3$) | 0.27 | 41.74 | 31.75 | 20.24 | 1.07 | 1.77 | 0.94 | - | 1.85 | 0.37 | | |

| | | |
|---|---|---|
| QUALITY FACTORS: | B/A Ratio: 0.58<br>Dol. Ratio: 0.07<br>Si/Al: 2.06 | Foul Index: 0.21<br>$Fe_2O_3$/CaO: 17.96<br>Si. Value: 0.55 |

*Ash sample: as fired composite from electrostatic precipitator hoppers. (Sept. 1980)

## APPENDIX C

## FLUE GAS DATA (FOR TEST NO. 72)

Due to the large volume of flue gas data, it is impractical to present all of it here. The data have already been summarized in Table B-III-3. The purpose of this appendix is to present an example of the detail upon which the summary is based. The results of Test No. 72 (the Level 1 test) are presented as an example of the detailed flue gas data kept for each test.

The first table is "as-measured" data (resulting from a computerized linearization of the raw data). Following the "as-measured" table, is a table of results normalized to a standard dilution (i.e.: 3% oxygen). All data are on a dry basis and have been adjusted to factor out leaks.

The sampling location was between the economizer and air heater.

## FLUE GAS ANALYSIS "AS MEASURED" DRY, TEST NO. 72 (9-10-83)

### C&SOE, CONESVILLE UNIT NO. 5
Level 1 Test
(Pg 1 of 2)

| PROBE | TIME | $O_2$ (PCT) | $NO_x$ (CHEMI) (PPM) | NO (CHEMI) (PPM) | CO (PPM) | $CO_2$ (PCT) |
|---|---|---|---|---|---|---|
| 1 | 12:13 to 12:44 | 4.50 | 280. | 280. | 4. | 13.45 |
| 2 | | 5.00 | 280. | 280. | 4. | 13.21 |
| 3 | | 6.90 | 260. | 260. | 4. | 11.12 |
| 4 | | 6.70 | 280. | 275. | 8. | 11.34 |
| 1 | | 4.70 | 270. | 270. | 4. | 13.21 |
| 2 | | 4.90 | 280. | 270. | 2. | 13.21 |
| 3 | | 6.50 | 250. | 250. | 2. | 11.34 |
| 4 | | 6.10 | 270. | 260. | 4. | 12.02 |
| 1 | | 4.60 | 280. | 275. | 4. | 13.21 |
| 2 | | 5.00 | 275. | 275. | 2. | 12.97 |
| 3 | | 6.80 | 255. | 250. | 2. | 10.89 |
| 4 | | 6.30 | 265. | 260. | 6. | 11.56 |
| 1 | 14:46 to 15:15 | 4.20 | 280. | 280. | 4. | 13.45 |
| 2 | | 4.70 | 275. | 270. | 4. | 13.21 |
| 3 | | 6.70 | 250. | 250. | 2. | 11.12 |
| 4 | | 6.30 | 260. | 255. | 4. | 11.34 |
| 1 | | 5.00 | 285. | 285. | 4. | 13.70 |
| 2 | | 4.90 | 280. | 275. | 8. | 14.20 |
| 3 | | 12.00* | 145. | 140. | 4. | 7.07 |
| 4 | | 6.20 | 270. | 260. | 10. | 12.49 |
| 1 | | 4.40 | 280. | 280. | 10. | 13.95 |
| 2 | | 5.00 | 280. | 275. | 10. | 13.07 |
| 3 | | 12.00* | 145. | 140. | 6. | 7.07 |
| 4 | | 6.10 | 265. | 265. | 14. | 12.26 |
| 1 | | 4.30 | 280. | 280. | 10. | 13.95 |
| 2 | | 4.70 | 280. | 275. | 12. | 13.95 |
| 3 | | 12.20* | 145. | 140. | 4. | 6.89 |
| 4 | | 6.10 | 265. | 265. | 12. | 12.49 |
| 1 | | 4.60 | 285. | 285. | 12. | 14.20 |
| 2 | | 5.00 | 280. | 280. | 8. | 13.70 |
| 3 | | 12.10 | 145. | 140. | 6. | 7.07 |
| 4 | | 6.50 | 265. | 260. | 14. | 12.26 |
| 1 | | 4.30 | 280. | 280. | 10. | 14.20 |
| 2 | | 4.90 | 280. | 275. | 10. | 13.95 |
| 3 | | 12.10* | 140. | 140. | 4. | 6.89 |
| 4 | | 6.00 | 270. | 265. | 12. | 12.97 |
| 1 | 16:35 to 16:46 | 4.40 | 290. | 285. | 8. | 14.71 |
| 2 | | 5.00 | 280. | 280. | 16. | 13.95 |
| 3 | | 5.20 | 280. | 280. | 18. | 13.45 |
| 4 | | 6.30 | 280. | 270. | 24. | 12.26 |
| 1 | | 4.40 | 295. | 290. | 16. | 14.46 |
| 2 | | 4.70 | 285. | 280. | 16. | 14.46 |
| 3 | | 5.20 | 285. | 280. | 18. | 13.45 |
| 4 | | 6.50 | 260. | 255. | 22. | 12.26 |
| 1 | | 4.40 | 300. | 290. | 16. | 14.46 |
| 2 | | 4.90 | 280. | 280. | 20. | 14.46 |
| 3 | | 5.10 | 280. | 280. | 20. | 13.70 |
| 4 | | 6.40 | 280. | 280. | 26. | 12.26 |

*Leak

(Continued)

## "AS MEASURED" TABLE
(CONTINUED — pg 2 of 2)

| PROBE | TIME | O (%) | $NO_x$ (PPM) | NO (PPM) | CO (PPM) | $CO_2$ (%)$^2$ |
|---|---|---|---|---|---|---|
| 1 | | 6.80 | 325. | 320. | 44. | 14.71 |
| 2 | | 5.00 | 295. | 290. | 44. | 13.95 |
| 3 | 17:28 | 5.20 | 285. | 285. | 6. | 13.70 |
| 4 | to | 7.80 | 250. | 245. | 12. | 11.12 |
| 1 | 17:44 | 4.50 | 300. | 300. | 18. | 14.46 |
| 2 | | 5.20 | 280. | 280. | 18. | 13.70 |
| 3 | | 5.30 | 285. | 280. | 22. | 13.45 |
| 4 | | 7.60 | 255. | 250. | 18. | 11.56 |
| 1 | | 4.00 | 310. | 300. | 20. | 14.71 |
| 2 | | 5.00 | 290. | 290. | 20. | 14.20 |
| 3 | | 5.50 | 295. | 290. | 22. | 13.45 |
| 4 | | 7.20 | 280. | 280. | 22. | 12.26 |
| 1 | | 4.50 | 340. | 340. | 20. | 13.95 |
| 2 | | 5.20 | 315. | 310. | 22. | 13.70 |
| 3 | | 5.20 | 305. | 300. | 22. | 12.73 |
| 4 | 18:28 | 5.90 | 285. | 280. | 28. | 12.26 |
| 1 | to | 3.60 | 325. | 320. | 24. | 14.71 |
| 2 | 18:42 | 4.70 | 310. | 310. | 24. | 13.95 |
| 3 | | 5.20 | 300. | 295. | 26. | 12.97 |
| 4 | | 6.30 | 290. | 285. | 28. | 12.49 |
| 1 | | 4.20 | 330. | 325. | 26. | 14.46 |
| 2 | | 5.30 | 320. | 315. | 26. | 13.45 |
| 3 | | 5.30 | 300. | 300. | 30. | 13.21 |
| 4 | | 6.30 | 290. | 285. | 26. | 12.26 |
| 1 | | 3.70 | 340. | 330. | 22. | 14.20 |
| 2 | | 5.10 | 315. | 310. | 26. | 13.45 |
| 3 | | 5.00 | 310. | 305. | 30. | 13.21 |
| 4 | | 5.90 | 295. | 295. | 30. | 12.49 |
| 1 | 19:28 | 3.80 | 335. | 330. | 32. | 14.71 |
| 2 | to | 5.50 | 305. | 300. | 32. | 12.97 |
| 3 | 19:43 | 5.30 | 320. | 320. | 34. | 13.21 |
| 4 | | 6.80 | 300. | 295. | 34. | 12.26 |
| 1 | | 4.30 | 345. | 340. | 34. | 14.20 |
| 2 | | 5.30 | 315. | 310. | 36. | 13.45 |
| 3 | | 5.00 | 310. | 305. | 36. | 13.70 |
| 4 | | 6.20 | 290. | 285. | 42. | 12.73 |
| 1 | | 3.80 | 335. | 330. | 30. | 14.71 |
| 2 | | 5.70 | 300. | 290. | 32. | 12.49 |
| 3 | | 5.00 | 310. | 305. | 32. | 13.70 |
| 4 | | 5.70 | 290. | 285. | 24. | 12.97 |
| 1 | 20:30 | 4.00 | 330. | 325. | 30. | 14.71 |
| 2 | to | 6.60 | 280. | 280. | 32. | 12.49 |
| 3 | 20:46 | 5.20 | 315. | 310. | 34. | 13.70 |
| 4 | | 7.00 | 295. | 290. | 34. | 12.26 |
| 1 | | 4.00 | 335. | 330. | 34. | 14.46 |
| 2 | | 6.80 | 280. | 275. | 36. | 12.26 |
| 3 | | 5.50 | 300. | 295. | 36. | 13.45 |
| 4 | | 6.30 | 290. | 285. | 40. | 12.73 |
| 1 | | 3.80 | 345. | 340. | 22. | 14.46 |
| 2 | | 7.10 | 280. | 275. | 24. | 11.12 |
| 3 | | 5.00 | 325. | 320. | 28. | 12.97 |
| 4 | | 5.90 | 300. | 295. | 30. | 12.49 |
| 1 | | 3.70 | 340. | 340. | 32. | 14.97 |
| 2 | 21:46 | 7.70 | 275. | 270. | 30. | 11.12 |
| 3 | to | 5.10 | 325. | 320. | 32. | 13.45 |
| 4 | 21:46 | 6.60 | 305. | 300. | 34. | 12.02 |
| 1 | | 4.20 | 350. | 340. | 34. | 14.71 |
| 2 | | 8.50 | 265. | 260. | 32. | 10.46 |
| 3 | | 5.00 | 320. | 320. | 34. | 13.45 |
| 6 | | 6.50 | 305. | 300. | 36. | 12.26 |
| | END | | | | | |

## TEST NO. 72: (LEVEL 1 TEST)
## CORRECTED TO 3% O2 (DRY BASIS)
## (Pg 1 of 2)

Station - CASOS, Conesville No. 5 (9/10/80)

| PROBE | $O_2$ (PCT) (MEAS) | $NO_x$ (CHEMI) (PPM) | NO (CHEMI) (PPM) | CO (PPM) | $CO_2$ (PCT) |
|---|---|---|---|---|---|
| 1 | 4.50 | 305. | 305. | 4. | 14.68 |
| 2 | 5.00 | 315. | 315. | 4. | 14.86 |
| 3 | 6.90 | 332. | 332. | 5. | 14.19 |
| 4 | 6.70 | 352. | 346. | 10. | 14.27 |
| 1 | 4.70 | 298. | 298. | 4. | 14.39 |
| 2 | 4.90 | 313. | 302. | 2. | 14.77 |
| 3 | 6.50 | 310. | 310. | 2. | 14.08 |
| 4 | 6.10 | 326. | 316. | 5. | 14.52 |
| 1 | 4.60 | 407. | 302. | 4. | 14.50 |
| 2 | 5.00 | 309. | 309. | 2. | 14.59 |
| 3 | 6.80 | 323. | 317. | 3. | 13.81 |
| 4 | 6.30 | 324. | 318. | 7. | 14.16 |
| 1 | 4.20 | 300. | 300. | 4. | 14.61 |
| 2 | 4.70 | 304. | 298. | 4. | 14.59 |
| 3 | 6.70 | 315. | 315. | 3. | 13.99 |
| 4 | 6.30 | 318. | 312. | 5. | 13.88 |
| 1 | 5.00 | 321. | 321. | 4. | 15.41 |
| 2 | 4.90 | 313. | 307. | 9. | 15.88 |
| 3 | Leak | 290. | 280. | 8. | 14.16 |
| 4 | 6.20 | 328. | 316. | 12. | 15.19 |
| 1 | 4.40 | 304. | 304. | 11. | 15.13 |
| 2 | 5.00 | 315. | 309. | 11. | 15.41 |
| 3 | Leak | 290. | 280. | 12. | 14.14 |
| 4 | 6.10 | 320. | 320. | 17. | 14.81 |
| 1 | 4.30 | 302. | 302. | 11. | 15.04 |
| 2 | 4.70 | 309. | 304. | 13. | 15.40 |
| 3 | Leak | 297. | 286. | 8. | 14.09 |
| 4 | 6.10 | 320. | 320. | 14. | 15.09 |
| 1 | 4.60 | 313. | 313. | 13. | 15.39 |
| 2 | 5.00 | 315. | 315. | 9. | 15.41 |
| 3 | Leak | 293. | 283. | 12. | 14.30 |
| 4 | 6.50 | 329. | 323. | 17. | 15.21 |
| 1 | 4.30 | 302. | 302. | 11. | 15.31 |
| 2 | 4.90 | 313. | 307. | 11. | 15.60 |
| 3 | Leak | 283. | 283. | 8. | 13.93 |
| 4 | 6.00 | 324. | 318. | 14. | 15.36 |
| 1 | 4.40 | 314. | 309. | 9. | 15.67 |
| 2 | 5.00 | 315. | 315. | 18. | 15.69 |
| 3 | 5.20 | 319. | 319. | 21. | 15.33 |
| 4 | 6.30 | 343. | 331. | 29. | 15.01 |
| 1 | 4.40 | 320. | 314. | 17. | 15.39 |
| 2 | 4.70 | 315. | 309. | 18. | 15.96 |
| 3 | 5.20 | 325. | 319. | 21. | 15.33 |
| 4 | 6.50 | 323. | 317. | 27. | 15.21 |
| 1 | 4.40 | 325. | 314. | 17. | 15.67 |
| 2 | 4.90 | 313. | 313. | 22. | 16.16 |
| 3 | 5.10 | 317. | 317. | 23. | 15.31 |
| 4 | 6.40 | 345. | 345. | 32. | 15.11 |
| 1 | 6.80 | 412. | 406. | 36. | 18.65 |
| 2 | 5.00 | 332. | 326. | 50. | 15.69 |
| 3 | 5.20 | 323. | 325. | 7. | 15.61 |
| 4 | 7.60 | 341. | 336. | 16. | 15.16 |
| 1 | 4.50 | 327. | 327. | 20. | 15.77 |
| 2 | 5.20 | 319. | 319. | 21. | 51.61 |
| 3 | 5.30 | 327. | 321. | 25. | 15.42 |
| 4 | 7.60 | 343. | 336. | 24. | 15.33 |

(Continued)

LEVEL RESULTS CORRECTED TO 3% O2
(CONTINUED) — pg 2 of 2)

| | PROBE | $O_2$ (%) | $NO_x$ (PPM) | NO (PPM) | CO (PPM) | $CO_2$ (PCT) |
|---|---|---|---|---|---|---|
| | 1 | 4.00 | 328. | 318. | 21. | 15.58 |
| | 2 | 5.00 | 326. | 326. | 23. | 15.98 |
| | 3 | 5.50 | 343. | 337. | 26. | 15.62 |
| | 4 | 7.20 | 365. | 365. | 29. | 15.99 |
| | 1 | 4.30 | 371. | 371. | 22. | 15.22 |
| | 2 | 5.20 | 359. | 353. | 25. | 15.61 |
| | 3 | 5.20 | 347. | 342. | 25. | 14.50 |
| | 4 | 5.90 | 340. | 334. | 33. | 14.61 |
| | 1 | 3.60 | 336. | 331. | 25. | 15.22 |
| | 2 | 4.70 | 342. | 342. | 27. | 15.40 |
| | 3 | 5.20 | 342. | 336. | 30. | 14.77 |
| | 4 | 6.30 | 360. | 354. | 35. | 15.31 |
| | 1 | 4.20 | 354. | 348. | 28. | 15.49 |
| | 2 | 5.30 | 367. | 361. | 30. | 15.42 |
| | 3 | 5.30 | 344. | 344. | 34. | 15.14 |
| | 4 | 6.50 | 360. | 354. | 32. | 15.21 |
| | 1 | 3.20 | 354. | 343. | 23. | 14.78 |
| | 2 | 5.10 | 357. | 351. | 29. | 15.23 |
| | 3 | 5.00 | 349. | 343. | 34. | 14.86 |
| | 4 | 5.90 | 352. | 352. | 36. | 14.89 |
| | 1 | 3.80 | 351. | 345. | 33. | 15.40 |
| | 2 | 5.50 | 354. | 348. | 37. | 15.06 |
| | 3 | 5.30 | 367. | 367. | 39. | 15.14 |
| | 4 | 6.80 | 380. | 374. | 43. | 15.56 |
| | 1 | 4.30 | 372. | 366. | 37. | 15.31 |
| | 2 | 5.30 | 361. | 355. | 41. | 15.42 |
| | 3 | 5.00 | 349. | 343. | 41. | 15.61 |
| | 4 | 6.20 | 353. | 347. | 51. | 15.48 |
| | 1 | 3.80 | 351. | 345. | 31. | 15.40 |
| | 2 | 5.70 | 353. | 341. | 38. | 14.69 |
| | 3 | 5.00 | 349. | 343. | 36. | 15.41 |
| | 4 | 5.70 | 341. | 335. | 28. | 15.26 |
| | 1 | 4.00 | 349. | 344. | 32. | 15.58 |
| | 2 | 6.80 | 355. | 355. | 41. | 15.83 |
| | 3 | 5.20 | 359. | 353. | 39. | 15.61 |
| | 4 | 7.00 | 379. | 373. | 44. | 15.76 |
| | 1 | 4.00 | 355. | 349. | 36. | 15.31 |
| | 2 | 6.80 | 355. | 349. | 46. | 15.54 |
| | 3 | 5.50 | 348. | 343. | 42. | 15.62 |
| | 4 | 6.30 | 355. | 349. | 49. | 15.59 |
| | 1 | 3.80 | 361. | 356. | 23. | 15.13 |
| | 2 | 7.10 | 363. | 356. | 31. | 14.39 |
| | 3 | 5.00 | 366. | 360. | 32. | 14.59 |
| | 4 | 5.90 | 358. | 352. | 36. | 14.89 |
| | 1 | 3.70 | 354. | 354. | 33. | 15.58 |
| | 2 | 7.70 | 372. | 365. | 41. | 15.04 |
| | 3 | 5.10 | 368. | 362. | 36. | 15.23 |
| | 4 | 6.60 | 381. | 375. | 43. | 15.03 |
| | 1 | 4.20 | 375. | 364. | 36. | 15.76 |
| | 2 | 8.50 | 382. | 374. | 46. | 15.06 |
| | 3 | 5.00 | 360. | 360. | 38. | 15.14 |
| | 4 | 6.50 | 379. | 372. | 45. | 15.21 |
| Averages | 1 | 4.32 | 336. | 332. | 21. | 15.41 |
| | 2 | 5.47 | 335. | 331. | 24. | 15.34 |
| | 3 | 5.47 | 331. | 327. | 22. | 14.85 |
| | 4 | 6.44 | 346. | 340. | 27. | 15.10 |
| | 1&2 | 4.89 | 335. | 331. | 23. | 15.38 |
| | 3&4 | 5.95 | 338. | 333. | 25. | 14.97 |
| | 1,2,3,&4 | 5.42 | 337. | 332. | 24. | 15.18 |

# APPENDIX D

## CONVERSION FACTORS, F FACTORS, AND SAMPLE CALCULATIONS

$$*\ \boxed{\left(\begin{array}{c}\text{Concentration Corrected to}\\ \text{X\% } O_2 \text{ Dilution}\end{array}\right) = \left(\begin{array}{c}\text{Actually Measured}\\ \text{Concentration at}\\ \text{Actual } O_2\\ \text{Dilution (Y\% } O_2)\end{array}\right)\left(\frac{21 - X}{21 - Y}\right)}$$

Example: 400 ppm $NO_x$ @ 4% $O_2$ = 423.5 ppm @ 3% $O_2$.

$$*\ \boxed{\left(\begin{array}{c}\text{Flow Rate}\\ \text{Corrected to X\% } O_2\end{array}\right) = \left(\begin{array}{c}\text{Flow Rate At}\\ \text{Y\% } O_2\end{array}\right) \cdot \left(\frac{21 - Y}{21 - X}\right)}$$

Example: A gas having flow rate 10 $ft^3$/min at 4% $O_2$ would have flow rate 9.444 at 3% $O_2$. (Assuming all other conditions - % moisture, temp, pres - remain unchanged.)

$$\boxed{\left(\begin{array}{c}\text{Concentration}\\ \text{on Dry Basis}\end{array}\right) = \left(\begin{array}{c}\text{Concentration}\\ \text{on Wet Basis}\end{array}\right)\left(\frac{1}{1 - \text{(fraction of moisture)}}\right)}$$

Example: If $SO_2$ has concentration 2.00 g/WSCF** in a gas containing 10% $H_2O$ vapor by volume, then its concentration on a dry basis would be:

$$\left(\begin{array}{c}\text{Concentration}\\ \text{on Dry Basis}\end{array}\right) = \left(2.0\ \frac{g}{ft^3}\right)\left(\frac{1}{1 - 0.10}\right) = 2.22\ \text{g/DSCF}$$

$$\boxed{\text{ppm} = \frac{\left(\begin{array}{c}\text{Concentration by weight } (g/m^3)\\ \text{at temperature T } (^\circ K)\\ \text{and pressure P (Atm)}\end{array}\right)}{\left(\begin{array}{c}\text{molecular}\\ \text{weight}\end{array} : \frac{g}{\text{g Mole}}\right)}\left(82.05^{***}\right)\left(\frac{T\ (^\circ K)}{P\ (\text{Atm})}\right)}$$

---

*These formulas assume that oxygen can enter or leave the system only in the form of air. That is: every volume of $O_2$ crossing the system boundary is accompanied by 3.76 volumes of inert gas. (Air is 21% $O_2$.)

**WSCF = Wet Standard Cubic Foot (68°F, 1 Atm).

***82.05 is the value of "R," the universal gas constant, and has units of

$$\frac{cm^3\ \text{Atm}}{\text{gMole}\ ^\circ K}$$

Example: Suppose $SO_3$ (molecular weight = 80 g/g mole) has a concentration (by weight) of 300 mg/DSCM.* What is its concentration in parts per million?

$$\text{ppm} = \left(\frac{0.300}{80}\right)\left(82.05\right)\left(\frac{293}{1}\right) = 90.15 \text{ ppm Dry}$$

Since the original concentration was given on a dry basis, the converted result is also still on a dry basis.

Of course, the above equation may be rearranged to facilitate conversion from ppm to grams/meter$^3$ at any temperature and pressure.

$$\boxed{\left(\begin{array}{c}\text{Concentration by weight } (g/m^3)\\ \text{At Temperature T...}(^oK)\\ \text{and Pressure P.....(Atm)}\end{array}\right) = \left(\frac{(\text{ppm})\left(\begin{array}{c}\text{Molecular wt}\\ \text{of specie}\\ \text{of interest}\\ \text{(g/gMole)}\end{array}\right)(P(\text{Atm}))}{\left(82.05\right)\left(T(^oK)\right)}\right)}$$

(The reader should note that this is valid for ordinarily encountered concentrations where the volume percent of the pollutant is small. That is: <~10,000 ppm)

## "F" FACTOR METHOD FOR CONVERTING TO THE STANDARD UNIT OF EMISSION: POUNDS/MBtu

The "F" factor method can be used to convert the emmission rate to the standard units of pounds per MBtu through of the following equation:***

$$\boxed{\left(\frac{\text{Pounds}}{\text{MBtu}}\right) = \left(\frac{\text{Pounds}}{\text{DSCF}}\right)^{**} \quad (F_d)\left(\frac{21}{21 - \%O_2}\right)}$$

Where: $\%O_2$ = Oxygen concentration at which the value marked by the double asterisk is valid.

$F_d$ = The "F" factor for the fuel being burned. It has units of DSCF/MBtu. (at 0% $O_2$)

For bituminous coal, the EPA-APTI training manual (referenced on the bottom of the page***) gives:

---

*DSCM = dry standard cubic meter. (T = 293$^o$K, and P = 1 Atm.)

**Obtained by conversion of the formula for "concentration by weight" listed on the preceding page.

***G. J. Aldina, J. A. Jahnke, "Source Sampling for Particulate Pollutants" pg. 140, manual for course No. 450 of EPA's Air Pollution Training Institute. Prepared by Northrup Services Inc., under EPA contract No. 68-02-2374, January 1978.

$$F_d = 9820 \ \frac{\text{DSCF}}{\text{MBtu}} \ (\text{at } 0\% \ O_2)$$

This assumes complete combustion, and no excess oxygen - an assumption already factored into the previous equation.

Rather than using the tabulated value for $F_d$, the value of $F_d$ may be calculated from fuel analysis according to the following formula (given on pg 145 of the above referenced manual):

$$F_d = \frac{10^6 \ (3.64\% \ H + 1.53\% \ C + 0.57\% \ S + 0.14\% \ N - 0.46\% \ O)}{\text{High Heating Value: Btu/lb}}$$

Plugging in values from Exxon's coal analysis from the Level 1 test of 9-10-80 (Appendix B) gives:

$$F_d = \frac{10^6[(3.64)(4.64)+(1.53)(66.02)+(0.57)(5.45)+(0.14)(1.40)-(0.46)(7.78)]}{12,124}$$

$$= 9702 \ \frac{\text{DSCF}}{\text{MBtu}} \ (\text{at } 0\% \ O_2)$$

This (9702) agrees reasonably well with the tabulated value (9820).

However, before this formula for converting to standard emission units can be used, the concentration of the pollutant specie of interest must first be expressed in units of $\frac{\text{Pounds}}{\text{DSCF}}$ at any known oxygen concentration.

As a first example, let us consider one of the GC results. This will be a good exercise since these are presently expressed in the worst possible units for use in the above equation, and must undergo several conversions in order to get them into appropriate units.

Most other emissions are already expressed in terms that are intermediate in the following example.

Each conversion uses one of the formulas (in original or rearranged form) given at the beginning of this appendix.

**EXAMPLE No. 1:**

GC results are reported as either "%" or "ppm" on a wet basis (5.95% $H_2O$) and at the duct's actual $O_2$ concentration. (5.4% $O_2$ - Dry Basis - from van readings).

- Converting to dry basis:

  The $SO_2$ reading, for example, is given as 2170 ppm (0.217%) by volume. Correcting this to a dry basis is done by factoring out the 0.0595 fraction of water:

$$(\text{ppm } SO_2 \text{ Dry Basis}) = (\text{ppm } SO_2 \text{ Wet Basis})/(1 - 0.0595)$$

$$= 2307 \text{ ppm } SO_2 \text{ (Dry Basis at 5.4\% } O_2\text{)}.$$

- Converting to 3% $O_2$:

  Correcting the dry basis from 5.4% $O_2$ to 3% $O_2$ is done as follows:

$$\left(\frac{21 - 3}{21 - 5.4}\right)(2307) = 2661 \text{ ppm } SO_2 \text{ at 3\% } O_2\text{, Dry Basis}$$

- Converting to units of mass or weight at standard conditions (STP) is done as follows:

$$\left(\frac{g}{m^3}\right) = (\text{ppm})\left(\frac{g}{\text{g Mole}}\right)\Big/\left((82.05)\left\{\frac{T(^{\circ}K)}{P(Atm)}\right\}\right)$$

$$= \left((2661)(64)\right)\Big/\left((82.05)\left(\frac{293}{1}\right)\right)$$

$$= 7.08 \text{ g/m}^3 \left\{\begin{array}{l}\text{Since the "ppm" concentration fed into the} \\ \text{formula was on a dry basis at 3 vol \% } O_2\text{, this} \\ SO_2 \text{ concentration is still on a dry basis at} \\ \text{3\% (by volume) } O_2.\end{array}\right.$$

$$= 0.2006 \text{ g/DSCF}$$

$$= 4.423 \times 10^{-4} \text{ Pounds } SO_2\text{/DSCF (@ 3\% } O_2\text{)}$$

- Converting to standard units (weight per heat input):

  As explained a few paragraphs earlier...

$$\left(\frac{\text{Pounds}}{\text{MBtu}}\right) = \left(\frac{\text{Pounds}}{\text{DSCF}}\right)(F_d)\left(\frac{21}{21 - \%\ O_2}\right)$$

$$= (4.423 \times 10^{-4})(9702)\left(\frac{21}{21 - 3}\right)$$

$$= 5.01 \ \frac{\text{Pounds of } SO_2}{10^6 \text{ Btu}}$$

This is the rate at which $SO_2$ is leaving the boiler on its way to the pollution control devices.

**EXAMPLE No. 2 (SASS):**

SASS results arrive initially in terms of "weight per total sample." For example, the chemist may have found that the total sample contained "X" grams of particulate. Using the values given on Table GH-2 (Appendix H), one finds that, for this SASS run, X/741.6 is the concentration expressed on a mass per volume of gas basis. Specifically, X/741.6 is the weight per DSCF at standard dry conditions (0.0% $H_2O$, 6.65% $O_2$, 68°F, 29.92 in Hg) and has units of $g/ft^3$.

Correcting to 0.0% $O_2$ gives:

$$\left(\frac{X}{741.6}\right)\left(\frac{21}{21 - 6.65}\right) = (0.001973)(X)$$

This expression has units of $\frac{g}{DSCF}$ (at 0% $O_2$)

Multiplying by the F - Factor gives:

$$\left(0.001973X \ \frac{g}{DSCF\ (at\ 0\%\ O_2)}\right)\left(9702^{*} \ \frac{DSCF\ (at\ 0\%\ O_2)}{MBtu}\right) = 19.15X \ \frac{g}{MBtu}$$

In other words: To convert any of these SASS results from "weight per total sample" to "weight per MBtu," simply multiply by 19.15.** Similarly, for metric units (weight per Joule), the factor is $1.82 \times 10^{-8}$.

## HEAT INPUT RATE

Several methods (listed below) have been used to find the heat input rate to the boiler during the Level 1 test.

- F - Factor Method

  From Entropy's report (Appendix F) ........................ 4637 $\frac{MBtu}{Hr}$

- From ER&E coal analysis (Appendix B) and feed rate

  $\left(11,843 \ \frac{Btu}{pound(wet)}\right)\left(360,000 \ \frac{Pounds(wet)}{Hr}\right)$ = ................ 4263 $\frac{MBtu}{Hr}$

- Average of the above ............................................ 4450 $\frac{MBtu}{Hr}$

## FLOW RATES OF FLUE GASES (at 0% $O_2$, Dry)

Measured values (from Appendixes C and F)

- Entering Precipitator

$$(1,006,000\ DSCF/min)\left(\frac{21 - 6.65}{21}\right) = \ldots\ldots\ldots\ 687,000\ DSCF/min\ (at\ 0\%\ O_2)$$

---

*Calculated earlier in this appendix.

**1/19.15 (or 0.0522) is the number of MBtu's of coal that had to be burned to produce the amount of flue gas sampled during this test.

- Leaving Precipitator

$$(1{,}113{,}000\ \text{DSCF/min})\left(\frac{21 - 6.65}{21}\right) = \ldots\ldots\ldots\ 761{,}000\ \text{DSCF/min (at 0\% } O_2)$$

Calculated value (from F-factor and fuel feed rate)

$$\left(9702\ \frac{\text{DSCF}}{\text{MBtu}}\right)\left(4450\ \frac{\text{MBtu}}{\text{Hr}}\right)\left(\frac{1}{60}\ \frac{\text{Hr}}{\text{Min}}\right) = \ldots\ldots\ldots\ldots\ 720{,}000\ \text{DSCF/min (at 0\% } O_2)$$

All values (3 different methods) agree reasonably well.

## CONVERSION FACTORS FOR COAL FIRED BOILER EMISSIONS

The values shown below are based on the following assumptions:

- At 0% excess air, complete combustion of bituminous coal produces 9820* standard cubic feet of gaseous combustion products (on a dry basis) per million Btu of heat content in the fuel. Similarly, on a wet basis (EPA assumes 8% moisture in the flue gas), the value is 10,680 WSCF/MBtu.*

- Typically, a pound of bituminous coal has a heat content of 11,000 Btu/pound (as fired basis: 10% moisture), or 12,000 Btu/pound (dry basis).

Other information about the heat content, "F" factors, and combustion products of various fuels (based on fuel analysis) may be found in the reference cited on the bottom of this page.**

| | |
|---|---|
| Coal Heat Content<br>(Bituminous Coal) | 11,000 Btu/lb (wet)<br>12,000 Btu/lb (dry) |
| Flue Gas Flow Rate*<br>(Assuming perfect combustion at 0% excess air) | 10,680 WSCF/MBtu<br>or<br>9,820 DSCF/MBtu |

---

*Based on "F" factors.

**G. J. Aldina, J. A. Jahnke, "Source Sampling for Particulate Pollutants" pp. 138-153, manual for course No. 450 of EPA's Air Pollution Training Institute. Prepared by Northrup Services Inc., under EPA contract No. 68-02-2374, January 1978.

Typically, when operating near full load, a large (400 MW) coal fired steam generator (boiler) will burn about 43 tons of coal per hour for every 100 MW of electricity it produces.

If the heat content of the fuel is about 11,000 Btu/pound, then at full load (400 MW):

$$\left(\begin{matrix}\text{Emission Rate:}\\ \text{pounds/hour}\end{matrix}\right) = \left(\begin{matrix}\text{Emission Rate:}\\ \text{pounds/MBtu}\end{matrix}\right)\left(3800\ \text{MBtu/Hr}^{*}\right)$$

**Example:** A 400 MW boiler with particulate emissions of 0.7 lb/MBtu when at full load is emitting about 2700 pounds of particulate matter per hour.

---

$$^{*}\ (400\ \text{MW})\left(\frac{43\ \text{tons/hr}}{100\ \text{MW}}\right)\left(\frac{2000\ \text{pounds}}{\text{Ton}}\right)\left(\frac{11{,}000\ \text{Btu}}{\text{Pound}}\right) = 3800 \times 10^{6}\ \text{Btu/hour}$$

$$= 3800\ \text{MBtu/hr}$$

# CONVERSION FACTORS

## English and Metric Units to SI Units

| To Obtain | From | Multiply By |
|---|---|---|
| ng/J | lb/MBtu | 430 |
| ng/J | g/MCal | 239 |
| GJ $hr^{-1}$ $m^{-2}$ | MBH**/$ft^2$ | 11.356 |
| GJ $hr^{-1}$ $m^{-3}$ | MBH/$ft^3$ | 37.257 |
| GJ/hr | $10^3$ lb/hr* or MBH | 1.055 |
| MW | $10^3$ lb/hr* or MBH | 0.293 |
| m | ft | 0.3048 |
| cm | in | 2.54 |
| cm | mils | 0.00254 |
| $m^2$ | $ft^2$ | 0.0929 |
| $m^3$ | $ft^3$ | 0.02832 |
| Kg | lb | 0.4536 |
| °Kelvin | °Rankin | 5/9 |
| °Celsius | °Fahrenheit | $t_c = (5/9)(t_F-32)$ |
| °Kelvin | °Fahrenheit | $t_k = ((5/9)(t_F-32)) + 273$ |
| °Kelvin | °Celsius | $t_k = t_c + 273$ |
| Pa | psig | $P_{pa} = (P_{psig} + 14.7)(6895)$ |
| Pa | psia | $P_{pa} = (P_{psia})(6895)$ |
| Pa | iwg*** (39.2°F) | $P_{pa} = (P_{iwg})(249.1)$ |
| Pa | in Hg | 3385 |
| in $H_2O$ | in Hg | 13.6 |
| atm | in Hg | 1/760 |
| mmHg | in Hg | 25.4 |
| psi | in Hg | 0.491 |

| To Obtain ng/J for | Multiply Concentrations (in ppm dry at 3% $O_2$) by |
|---|---|
| **Natural Gas Fuel** | |
| CO | 0.310 |
| HC | 0.177 |
| $NO_x$, NO, or $NO_2$ (As Equivalent $NO_2$) | 0.510 |
| $SO_x$ ($SO_2$) | 0.709 |
| **Oil Fuel** | |
| CO | 0.341 |
| HC | 0.195 |
| $NO_x$, NO, or $NO_2$ (As Equivalent $NO_2$) | 0.561 |
| $SO_x$ ($SO_2$) | 0.780 |
| **Coal Fuel** | |
| CO | 0.372 |
| HC | 0.213 |
| NO | 0.395 |
| $NO_x$, NO, or $NO_2$ (As Equivalent $NO_2$) | 0.589 |
| $SO_x$ ($SO_2$) | 0.850 |

---

*lb/hr of equivalent saturated steam. (For water, the heat of the liquid-gas phase change is about $10^3$ Btu/pound.)

**$10^6$ Btu/hr

***The symbols iwg and in $H_2O$ g are used interchangeably in this report to indicate guage pressure in inches of water.

# CONVERSION FACTORS

## SI Units to Metric or English Units

| To Obtain | From | Multiply By |
|---|---|---|
| g/Mcal | ng/J | 0.004186 |
| $10^6$ Btu | GJ | 0.948 |
| MBH/$ft^2$ | $GJ \cdot hr^{-1} m^{-2}$ | 0.08806 |
| MBH**/$ft^3$ | $GJ \cdot hr^{-1} \cdot m^{-3}$ | 0.02684 |
| Btu | gm cal | $3.9685 \times 10^{-3}$ |
| $10^3$ lb/hr* or MBH | GJ/hr | 0.948 |
| $10^3$ lb/hr* or MBH | MW | 3.413 |
| lb/MBtu | ng/J | 0.00233 |
| ft | m | 3.281 |
| in | cm | 0.3937 |
| mils | cm | 393.7 |
| $ft^2$ | $m^2$ | 10.764 |
| $ft^3$ | $m^3$ | 35.314 |
| lb | Kg | 2.205 |
| °Rankin | °Kelvin | 1.80 |
| °Fahrenheit | °Celsius | $t_F = 9/5(t_c)+32$ |
| °Fahrenheit | °Kelvin | $t_F = 1.8\ T_k - 460$ |
| °Rankin | °Fahrenheit | $t_R = t_F + 460$ |
| psig | Pa | $P_{psig} = (P_{pa})(0.0001450)-14.7$ |
| psia | Pa | $P_{psia} = (P_{pa})(0.0001450)$ |
| iwg*** (39.2°F) | Pa | $P_{iwg} = (P_{pa})(0.004014)$ |
| in Hg | Pa | 0.000295 |
| in Hg | in $H_2O$ | 1/13.6 |
| in Hg | atm | 760 |
| in Hg | mm Hg | 1/25.4 |
| in Hg | psi | 2.036 |

| To Obtain ppm (dry) at 3% $O_2$ for | Multiply Flow Concentrations in ng/J, by |
|---|---|
| **Natural Gas Fuel** | |
| CO | 3.23 |
| HC | 5.65 |
| $NO_x$, NO, or $NO_2$ (As Equivalent $NO_2$) | 1.96 |
| $SO_x$ ($SO_2$) | 1.41 |
| **Oil Fuel** | |
| CO | 2.93 |
| HC | 5.13 |
| $NO_x$, NO, or $NO_2$ (As Equivalent $NO_2$) | 1.78 |
| $SO_x$ ($SO_2$) | 1.28 |
| **Coal Fuel** | |
| CO | 2.69 |
| HC | 4.69 |
| NO | 2.52 |
| $NO_x$, NO, or $NO_2$ (As Equivalent $NO_2$) | 1.71 |
| $SO_x$ ($SO_2$) | 1.18 |

---

*lb/hr of equivalent saturated steam. (For water, the heat of the liquid-gas phase change is about $10^3$ Btu/pound.)

**$10^6$ Btu/hr

***The symbols iwg and in $H_2O$ g are used interchangeably in this report to indicate guage pressure in inches of water.

## CONVERSION FACTORS

## ENGLISH TO SI UNITS

| To Convert From | To | Multiply By* |
|---|---|---|
| Btu | Gigajoule, GJ | 1.055 056 E-06 |
| MBtu/h | Megawatt, MW | 2.930 000 E-01 |
| Btu/lb | Gigajoule/kilogram, GJ/kg | 2.326 000 E-06 |
| Btu/lb | Calories/gram, cal/g | 5.559 273 E-01 |
| Pounds/square inch | Megapascal, MPa<br>Kilopascal, kPa | 6.894 757 E-03<br>6.894 757 E+00 |
| Pounds/hour, lb/h | Kilogram/hour, kg/h | 4.535 934 E-01 |
| Pounds/hour, lb/h | Metric tons/hour, t/h | 4.535 925 E-04 |
| Tons (short) | Metric tons, t | 9.071 847 E-01 |
| Pounds, lb | Kilogram, kg | 4.535 924 E-01 |
| Feet, ft | Metre, m | 3.048 000 E-01 |
| Square Feet, $ft^2$ | $Metres^2$, $m^2$ | 9.290 304 E-02 |
| Inches, in. | Centimetres, cm | 2.540 000 E-00 |
| Inches, in. | Metre, m | 2.540 000 E-02 |
| Grains/cubic foot | $Milligrams/metre^3$, $mg/m^3$ | 2.288 351 E-01 |
| Cubic feet, $ft^3$ | $Metre^3$, $m^3$<br>$Decimetre^3$, $dm^3$ | 2.831 685 E-02<br>2.831 685 E+01 |
| Gallons | $Metres^3$, $m^3$<br>$Decimetre^3$, $dm^3$ | 3.785 412 E-03<br>3.785 412 E+00 |

*Numbers expressed in power-of-ten notation using E + xx to indicate the power of ten. For example:

1.055 056 E-06 = 1.055 056 x $10^{-6}$ = .000001055056

# CONVERSION FACTORS FOR $NO_x$ AND $SO_2$ EMISSIONS FROM BITUMINOUS COAL COMBUSTION

| To Convert From | To | For $NO_x$* Emissions (as $NO_2$) Multiply By | For $SO_2$** Emissions Multiply By |
|---|---|---|---|
| ppm at 3% $O_2$ Dry | $\frac{g}{DSCM}$ at 3% $O_2$ | 0.0019134 | 0.001662 |
| $\frac{g}{DSCM}$ at 3% $O_2$ | $\frac{g}{DSCM}$ at 0% $O_2$ | 1.167 | 1.167 |
| $\frac{g}{DSCM}$ at 0% $O_2$ | $\frac{g}{DSCF}$ at 0% $O_2$ | 0.02832 | 0.02832 |
| $\frac{g}{DSCF}$ at 0% $O_2$ | $\frac{g}{MBtu}$ | 9,820 | 9,820 |
| $\frac{g}{MBtu}$ | $\frac{lb}{MBtu}$ | 0.002205 | 0.002205 |
| $\frac{lb}{MBtu}$ | $\frac{ng}{J}$ | 430 | 430 |

| | | | |
|---|---|---|---|
| ppm at 3% $O_2$ (dry) | lb/MBtu | 0.001369 | 0.00190 |
| ppm at 3% $O_2$ (dry) | ng/J | 0.5888 | 0.819 |

---

*In these calculations, consistent with EPA guidelines, $NO_x$ is treated as 100% $NO_2$ (molecular weight = 46 lb/lb Mole) since it is felt that all $NO_x$ is eventually converted in the atmosphere to $NO_2$. Actual flue gas measurements, however, indicate that $NO_x$ has a composition of about 5% $NO_2$ and 95% NO (MW = 30.8).

**Typically $SO_x$ emissions are >99% $SO_2$, and 1% $SO_3$. $SO_2$ molecular weight = 64.0 lb/lb mole.

## STANDARD CONDITIONS

EPA defines standard temperature and pressure (STP) as 20°C and 1 atm.

- o 20°C = 293°K = 68°F = 528°R
- o 1 atm = 760 mmHg = 29.92 in Hg = 14.7 psia = 406.8 in $H_2O$ = 101.3 kPa

## VOLUME ABBREVATIONS

$m^3$ = Cubic meters

SCM = Standard cubic meters

ACM = Actual cubic meters

WSCM = Standard cubic meters (wet basis)

DSCM = Standard cubic meters (dry basis)

$ft^3$ = Cubic feet

SCF = Standard cubic feet

ACF = Actual cubic feet

WSCF = Standard cubic feet (wet basis)

DSCF = Standard cubic feet (dry basis)

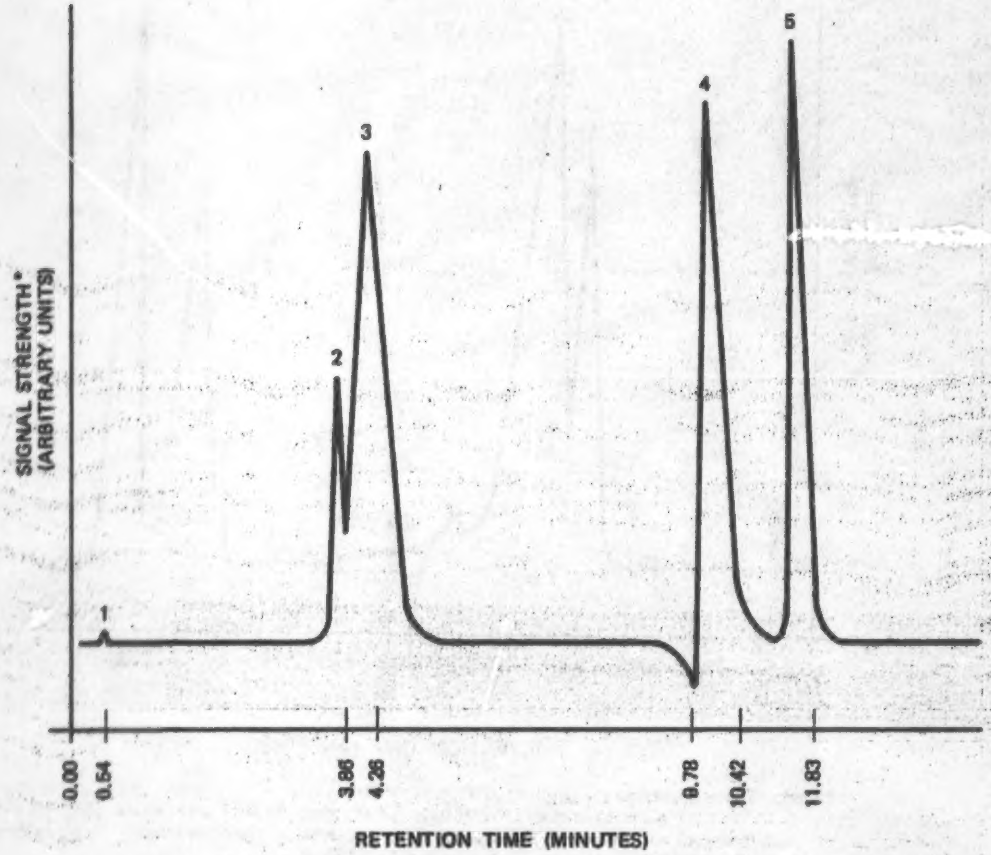
# APPENDIX E

## GC ANALYSIS DATA

The pages that follow contain raw GC data. At the beginning of each set of chromatograms (one for each type of analysis - permanent gases, sulfur compounds, hydrocarbons, etc.) is a narrative describing the results and problems, if any, related to that set of analyses.

## PERMANENT GAS ANALYSIS

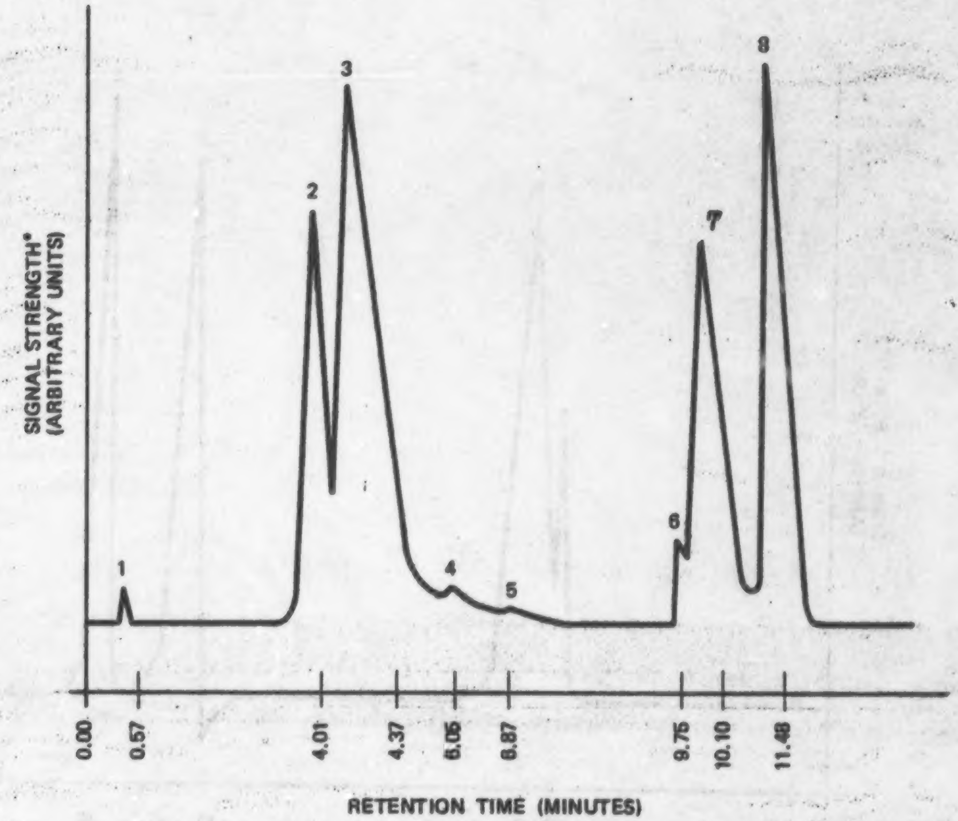
The "fixed" or "permanent" gases ($O_2$, $N_2$, $CO_2$, etc.) normally analyzed by continuous monitors were also analyzed by gas chromatography (CG) in advance of the Level 1 test. The chromatogram in Figure GE-2 clearly shows the presence of $O_2$, $N_2$, $H_2O$, $CO_2$ and other peaks that could indicate $H_2$, CO, and $CH_4$.



*Note: The attenuation (or gain) factor on the signal amplifier was changed many times during the test. The above tracing is useful only for showing the time and general shape of each peak. It should not be used to measure peak height, area, or response factor. Those calculations were performed by computer and are shown below.

| Peak Number | Retention Time (Minutes) | Probable Identification | Area Under Peak | Known Concentration In Sample (PCNT) | Response Factor (Area/PCNT) |
|---|---|---|---|---|---|
| 1 | 0.54 | Hydrogen | 123 | 1.0 | 123 |
| 2 | 3.86 | Oxygen | 742,000 | 3.8 | 195,000 |
| 3 | 4.26 | Nitrogen | 12,800,000 | 82.0 | 157,000 |
| 4 | 10.42 | Water | 701,000 | Unknown | – |
| 5 | 11.83 | Carbon Monoxide | 2,780,000 | 13.0 | 214,000 |

Figure GE-1 - GC CALIBRATION RUN FOR PERMANENT GASES



*Note: The attenuation (or gain) on the signal amplifier was changed many times during the run. The tracing shown above is useful only for showing the time and general shape of each peak. It should not be used to measure peak height, area, or response factor. Those calculations were performed by computor and are shown below.

| Peak Number | Retention Time (Minutes) | Probable Identification | Area Under Peak |
|---|---|---|---|
| 1 | 0.57 | Hydrogen | 1,430 |
| 2 | 4.01 | Oxygen | 155,000 |
| 3 | 4.37 | Nitrogen | 4,160,000 |
| 4 | 6.05 | Possibly CO | 414 |
| 5 | 6.87 | Unknown | 1,840 |
| 6 | 9.75 | Possibly Water Or Methane | 91,800 |
| 7 | 10.10 | Water | 544,000 |
| 8 | 11.48 | Carbon Monoxide | 936,000 |

Figure GE-2 - GC ANALYSIS FOR PERMANENT GASES

## HYDROCARBON ANALYSIS

The flame ionization detector is essentially a hydrogen-carbon bond counter. It responds almost exclusively to hydrocarbons and, within a family type (e.g.: straight chain, normal alkanes), gives a response factor (per volume concentration in gas) that is proportional to the carbon number. (On a mass basis, response factors will be more uniform.)

Also, within a family type (when the family type is known), there are certain rules (e.g.: Kovats Relative Index) that can be used to identify a hydrocarbon through measurement of the retention time of its peak.

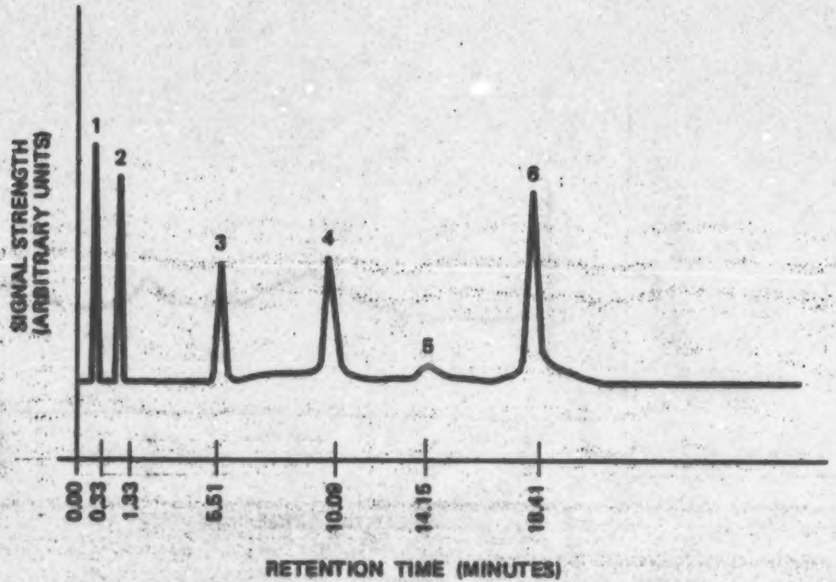
In the case of the flue-gas chromatograms shown in this section (Figures GE-4 and GE-6), it is fairly certain that most of the peaks are not due to normal straight chain alkanes since the peaks do not match those of the calibration runs (Figures GE-3 and GE-5). It is more likely that those peaks are due to more complex hydrocarbons and the peaks with longer retention times probably represent organic compounds having higher carbon numbers.

The 20% SP-2100 column (used for the analysis of the heavy hydrocarbons) is a "boiling point" column. (That is, it separates compounds according to their boiling points. And, since the flame ionization detector responds only to hydrocarbons, the resulting chromatogram for this column - detector combination is a trace of hydrocarbons separated according to boiling point. Generally, for relatively simple hydrocarbons, the boiling point depends on the carbon number to a larger degree than it does on the hydrocarbon type. Furthermore, retention time (relative to an unretained peak) will follow a logarithmic rule with a doubling of carbon number resulting in a quadrupling of retention time. These properties, when considered with the following chromatograms (Figures GE-4 and GE-6) indicate that no simple hydrocarbons were detected with carbon number greater than about $C_{10}$ and the volume percent of the high-boiling-point hydrocarbons was smaller than that of the lighter hydrocarbons. This may have been due to condensation of the heavier components of the sample upon the walls of the sample container after removal of the sample from the hot flue duct.

The calibration run for heavy hydrocarbons (Table GE-1) showed that for $nC_1$ through $nC_7$, the response per ng ranged from 1122 to 1882, with an average of 1522 area units per ng. (Alcohols are known to have slightly lower response factors.) For the heavy hydrocarbon calibration run, all such mass response factors were within a factor of three of the groups average. Hence, it is probably safe to assume that this average factor may be applied to the unknown peaks and will yield concentration values for the unknown substances that are correct within the accuracy required for Level 1 analysis.

Using this analytical procedure, the heavy hydrocarbon chromatogram, indicates that the large unknown peaks are due to complex organics having concentrations from 0.72 mg/m$^3$ to 5.57 mg/m$^3$ (with an average of 2.52 mg/m$^3$). Note that these multiple peaks were not seen during the light hydrocarbon analysis at this boiler. Nor were these heavy hydrocarbons seen at another boiler tested under this program.

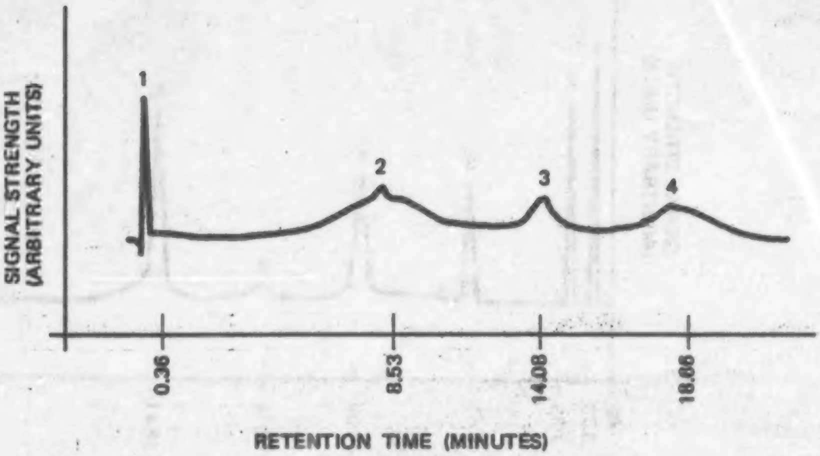
**If further work in this area is desired, it might be wise to consider the use of a mass spectrometer, to identify some of the unknown hydrocarbons. Alternatively, the injection of a single known liquid hydrocarbon could be used as a referance against which the relative retention times of the unknown peaks could be calculated with greater certainty.**



| Peak Number | Retention Time (Minutes) | Probable Identification | Area Under Peak | Known Concentration In Sample (PPM) | Response Factor (Area/ PPM) | Response Factor/ Carbon Number |
|---|---|---|---|---|---|---|
| 1 | 0.33 | $nC_1$ | 15,400 | 15.1 | 1020 | 1020 |
| 2 | 1.33 | $nC_2$ | 29,300 | 14.8 | 1980 | 990 |
| 3 | 5.51 | $nC_3$ | 44,000 | 15.7 | 2804 | 934 |
| 4 | 10.09 | $nC_4$ | 67,500 | 15.2 | 4443 | 1111 |
| 5 | 14.15 | Possibly A $C_5$ Isomer | 13,000 | Unknown | – | – |
| 6 | 18.41 | $nC_5$ | 123,000 | 16.2 | 7576 | 1515 |

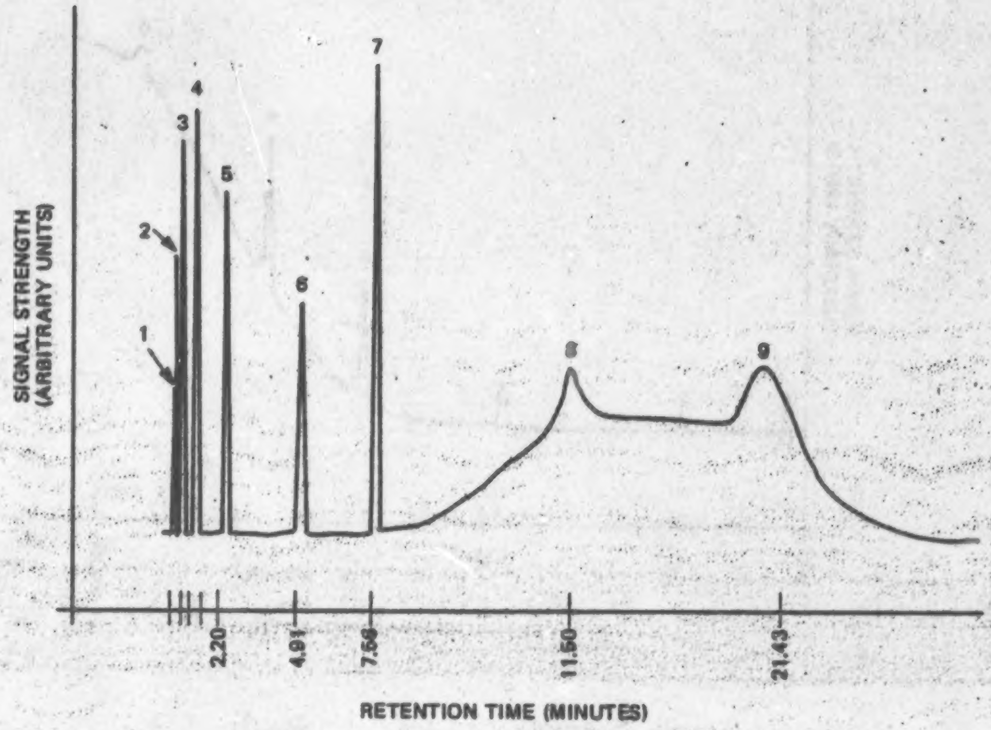
Average For $nC_1$ - $nC_5$ = 1114

Figure GE-3 - CALIBRATION RUN FOR LIGHT HYDROCARBONS



| Peak Number | Retention Time (Minutes) | Probable Identification | Area Under Peak | Calculated Concentration | |
|---|---|---|---|---|---|
| 1 | 0.36 | Unknown | 5,318 | — | — |
| 2 | 8.53 | Possibly includes nC$_4$ | 128,000 | $\frac{128,000}{4443/PPM}$ | = 28 PPM |
| 3 | 14.08 | Possibly A C$_5$ Isomer | 44,500 | — | — |
| 4 | 18.66 | nC$_5$ | 52,500 | $\frac{52,500}{7570/PPM}$ | = 7 PPM |

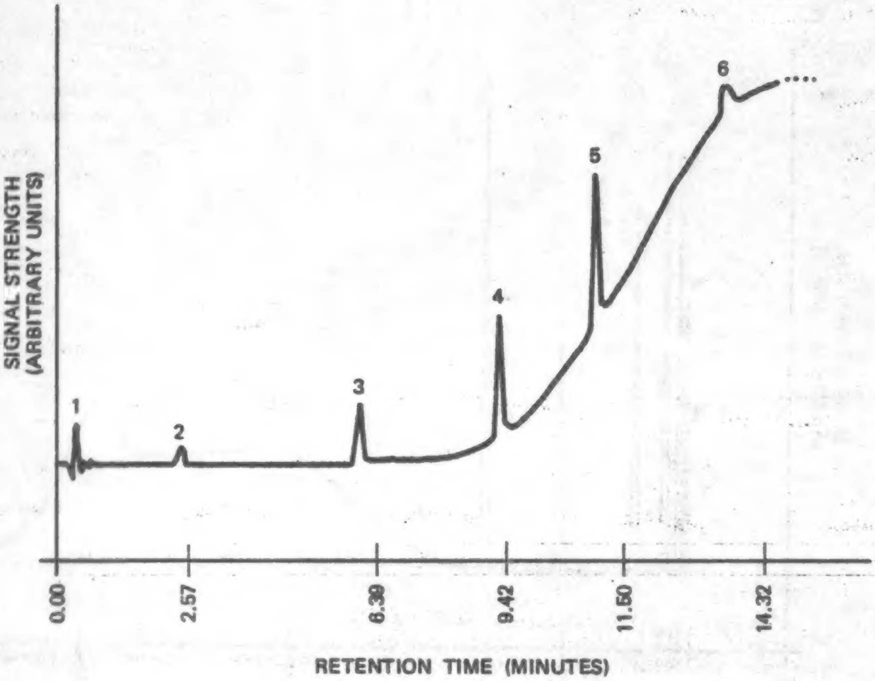
Figure GE-4 - GC ANALYSIS FOR LIGHT HYDROCARBONS



| Peak Number | Retention Time | Probable Identification | Area Under Peak | Known Concentration In Sample (PPM) | Calculated Response Factor (Area/Conc.) | Response Factor/ Carbon Number |
|---|---|---|---|---|---|---|
| 1 | 0.35 | $nC_1$ | 12,100 | 15.1 | 802 | 802 |
| 2 | 0.41 | $nC_2$ | 37,300 | 14.8 | 2,520 | 1260 |
| 3 | 0.53 | $nC_3$ | 48,400 | 15.7 | 3,080 | 1030 |
| 4 | 1.04 | $nC_4$ | 62,400 | 15.2 | 4,100 | 1030 |
| 5 | 2.20 | $nC_5$ | 78,700 | 16.2 | 4,860 | 972 |
| 6 | 4.91 | $nC_6$ | 86,000 | 17.1 | 5,030 | 838 |
| 7 | 7.56 | $nC_7$ | 97,800 | 13.1 | 7,460 | 1070 |
| 8 | 14.50 | Unknown | – | – | – | – |
| 9 | 21.43 | Unknown | – | – | – | – |

Average For $C_1$ - $C_7$ = 999

Figure GE-5 - CALIBRATION RUN FOR HEAVY HYDROCARBONS



| Peak Number | Retention Time (Minutes) | Area Under Peak | Calculated Concentration (ng/J)* |
|---|---|---|---|
| 1 | 0.37 | 1180 | 0.78 (1.1 PPM) |
| 2 | 2.57 | 1100 | 0.72 |
| 3 | 6.39 | 5020 | 3.30 |
| 4 | 9.42 | 4240 | 2.79 |
| 5 | 11.50 | 8470 | 5.57 |
| 6 | 14.32 | ~3000 | 1.97 |
|  |  | Average = | 2.52 |

* Based on an average assumed response factor of 1522 area units per ng (from table GE-1).

Figure GE-6 - GC ANALYSIS FOR HEAVY HYDROCARBONS

## TABLE GE-1

## HEAVY HYDROCARBON ANALYSIS - RESPONSE FACTORS*
(BASED ON FIGURE HE-6)

| Component | Concentration (ppm by volume) | Molecular Weight (g/gMole) | Nano-Grams** Injected | Response (Area Units) | Response Factor Area Units/ng |
|---|---|---|---|---|---|
| $nC_1$ | 15.1 | 16 | 10.79 | 12111 | 1122 |
| $nC_2$ | 14.8 | 30 | 19.82 | 37310 | 1882 |
| $nC_3$ | 15.7 | 44 | 30.83 | 48408 | 1570 |
| $nC_4$ | 15.2 | 58 | 39.36 | 62363 | 1584 |
| $nC_5$ | 16.2 | 72 | 52.07 | 78721 | 1512 |
| $nC_6$ | 17.1 | 86 | 65.65 | 85981 | 1310 |
| $nC_7$ | 13.1 | 100 | 58.48 | 97752 | 1672 |
|  |  |  |  |  | AVG 1522 |

*For a one cc injection.
**Assumes STP (one gMole occupies 22400 cc).

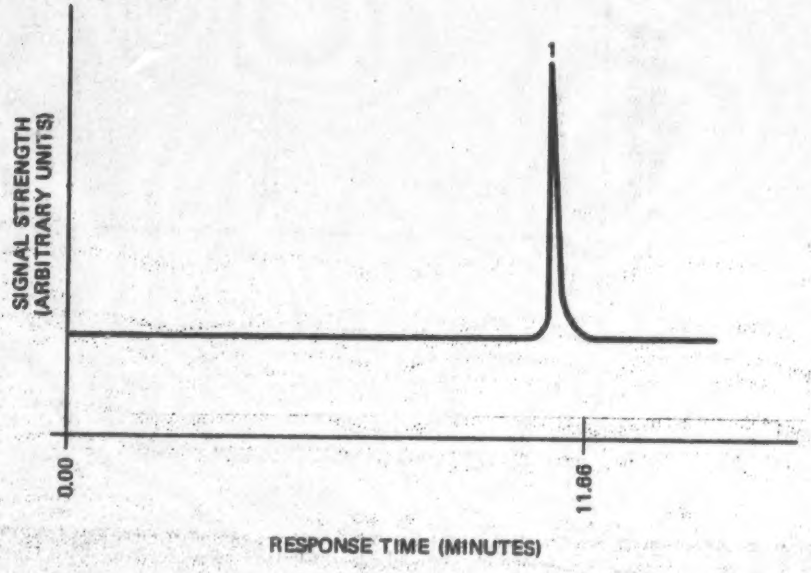
## SULFUR ANALYSIS

The chromatograms on the following pages (Figures GE-7 and GE-8) show the presence of $SO_2$ in amounts similar those measured by wet chemistry in earlier tests at this host site. The results are consistent with values predicted by fuel analysis. No other sulfur compounds (no other peaks) were detected during this Level 1 test at Conesville No. 5.

During the GC analysis for sulfur compounds:

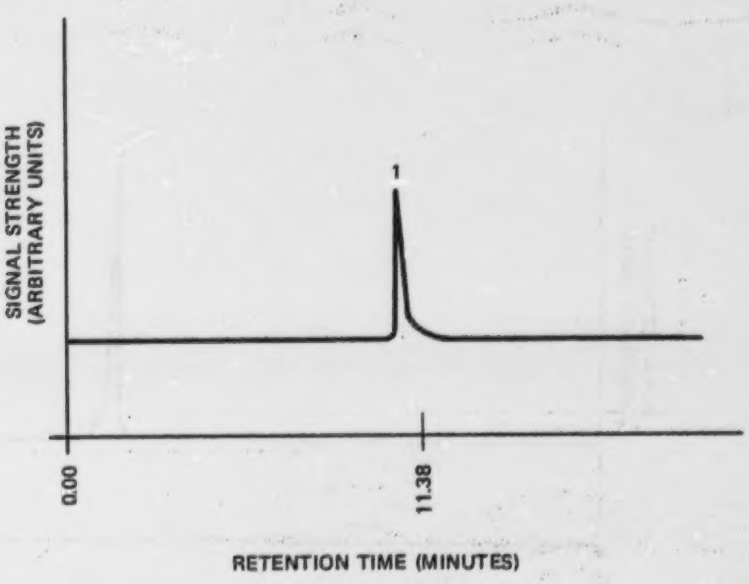
- Calibration gases of low concentrations (<1 ppm) could not be detected. Apparently, the shelf life of such low concentration gases is less than expected, and may be due to absorption of gas onto the cylinder walls.
- The 36 foot long column can be used only a short time before it begins to plug.
- It was impossible to eliminate all metal and rubber fittings from the gas flow system and the small amount used may have created some interferences.
- The column used (recommended by EPA) is not capable of separating $H_2S$ and COS.

Plans have already been made to correct some of these problems on subsequent tests. The solutions include preparing low concentration calibration gas mixtures onsite at the time of use so that degradation with time is minimized.



| Peak Number | Retention Time (Minutes) | Probable Identification | Peak Height | Known Concentration (PPM) |
|---|---|---|---|---|
| 1 | 11.66 | $SO_2$ | 4.5 cm (With Attenuation = 2) | 2123 |

Figure GE-7 - GC CALIBRATION RUN FOR $SO_2$ - TYPE COMPOUNDS



| Peak Number | Retention Time (Minutes) | Probable Identification | Peak Height |
|---|---|---|---|
| 1 | 11.38 | $SO_2$ | 2.3 cm (With Attenuation Set To 4) |

$SO_2$ Concentration Calculation:

$$\left(\frac{2123\ \text{PPM}}{4.5\ \text{cm}}\right)\left(\frac{\text{Attenuation} = 4}{\text{Attenuation} = 2}\right)(2.3\ \text{cm})\left(\frac{1\ \text{cc}}{1\ \text{cc}}\right) = 2170\ \text{PPM}$$

Figure GE-8 - GC ANALYSIS FOR SULFUR COMPOUNDS

# APPENDIX F

## PORTIONS OF METHOD 17 REPORTS
(By Entropy Environmentalists)

EPA Method 17 (similar to Method 5 except for the filter location) was used to measure particulate loading in the flue gas. The following pages contain selected data from Entropy Environmentalists' report of the Method 17 tests. Testing was done at the inlet to the precipitator, as well as at the outlet (simultaneously). Two such pairs of inlet/outlet tests (No. 1/No. 4, and No. 2/No. 5) were performed, thus allowing two evaluations of precipitator efficiency.

## SUMMARY OF RESULTS

Table 1 presents the particulate concentration found at the inlet and cutlet of the electrostatic precipitator. Using these concentrations, a collection efficiency, by weight, was calculated for each set of simultaneous inlet-outlet Method 17 tests. Individual test summaries are given in Tables 2 and 3 for the inlet and outlet tests, respectively.

### TABLE 1

### Unit #5 Emissions and Precipitator Collection Efficiencies

| Simultaneous Inlet-Outlet Test No. | Grains per dscf Inlet | Grains per dscf Outlet | Collection Efficiency,% | PPTR Outlet Pounds Per Million Btu |
|---|---|---|---|---|
| 1 & 4 | 3.104 | 0.0554 | 98.2 | 0.115 |
| 2 & 5 | 4.031 | 0.0667 | 98.3 | 0.138 |
| Average | 3.568 | 0.0611 | 98.3 | 0.126 |

## TABLE 2

## PARTICULATE TESTS SUMMARY OF RESULTS

### Unit 5, Precipitator Inlet

| | 1 | 2 | Average Value (Used in Report Calculations) |
|---|---|---|---|
| DATE | 9/10/80 | 9/10/80 | |
| STACK TEMPERATURE, DEG. F | 308. | 306. | |
| STACK FLOW RATE SCFM* DRY | 1018398. | 993183. | 1,005,790 |
| STACK FLOW RATE ACFM, WET | 1607617. | 1597721. | |
| VOLUME OF GAS SAMPLED SCF* DRY | 104.1 | 103.9 | |
| PERCENT ISOKINETIC | 100.5 | 103.0 | |
| METHOD 17 RESULTS: | | | |
| MILLIGRAMS CATCH | 20928.6 | 27155.0 | |
| GRAINS PER DSCF* | 3.1038 | 4.0314 | |
| POUNDS PER HOUR | 27093.36 | 34319.50 | |

* 68 DEG F, 29.92 IN. HG

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## TABLE 3

## PARTICULATE TESTS SUMMARY OF RESULTS

### Unit 5, Precipitator Outlet

| | 4 | 5 | Average Value** |
|---|---|---|---|
| DATE | 9/10/80 | 9/10/80 | |
| STACK TEMPERATURE, DEG. F | 308. | 308. | |
| STACK FLOW RATE SCFM* DRY | 1095978. | 1129906. | 1,112,942 |
| STACK FLOW RATE ACFM, WET | 1727079. | 1774033. | |
| VOLUME OF GAS SAMPLED SCF* DRY | 111.1 | 120.2 | |
| PERCENT EXCESS AIR | 46. | 45. | |
| HEAT INPUT RATE - F FACTOR MILLION BTU/HR | 4549.7 | 4723.6 | 4,637*** |
| PERCENT ISOKINETIC | 108.8 | 104.1 | |
| METHOD 17 RESULTS: | | | |
| MILLIGRAMS CATCH | 399.1 | 519.3 | |
| GRAINS PER DSCF* | .0554 | .0667 | |
| POUNDS PER HOUR | 520.76 | 645.80 | |
| POUNDS PER MILLION BTU | .1145 | .1367 | |

* 68 DEG F, 29.92 IN. HG

** Used for calculations in this report.

*** The heat input rates reported in this appendix are based strictly on the F-factor method as applied to Method 17 data and they agree fairly well with the value calculated in Appendix D which is based on the fuel's heat content and reported feed rate.

## PROCESS DESCRIPTION AND OPERATION

The Conesville Generating Station of Columbus and Southern Ohio Electric Company employs six coal-fired boilers for the production of steam to drive electric generating turbines. Unit 5 was tested on September 10, 1980.

Typically, the bituminous coal used for combustion in the boiler is first pulverized and then blown into the combustion chamber by exhaust fans. This provides simultaneous fuel suspension and combustion. From the firing chamber the combustion gases pass through an economizer, an air preheater and the electrostatic precipitator. The gases then split and pass through two I.D. fans, two scrubbers, and then pass into the stack and to the atmosphere. The two scrubbers can be bypassed by ducting the gases through the scrubbers bypass duct, as shown in Figure 1. For the testing program, the scrubbers were in operation and were not bypassed.

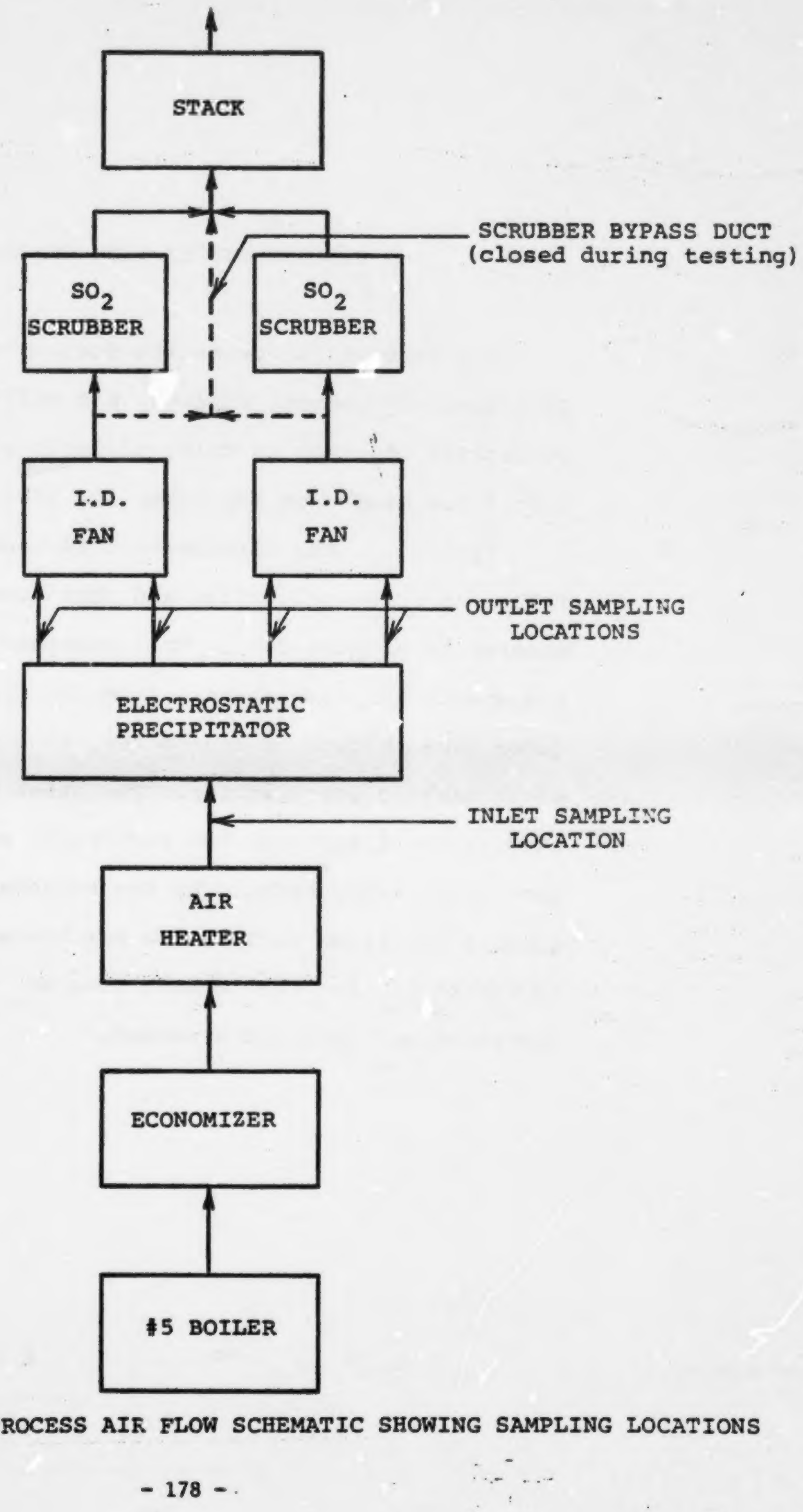


FIGURE 1. PROCESS AIR FLOW SCHEMATIC SHOWING SAMPLING LOCATIONS

# APPENDIX G

## CE'S REPORT OF CHARACTERIZATION TESTS 1-47

This appendix contains selections from a report of data analysis performed by Combustion Engineering Inc. (CE), the boiler's manufacturer. The report covers all characterization tests through number 47, and was reported to ER&E in May, 1980 by CE.

**C-E Power Systems**
Combustion Engineering, Inc.
1000 Prospect Hill Road
Windsor, Connecticut 06095

Tel. 203/688-1911
Telex: 99297

**POWER SYSTEMS**

May 2, 1980

Exxon Research and Engineering Company
Environmental Control Division
Post Office Box 101
Florham Park, New Jersey 07932

Attention: Mr. John M. Ferrarro

Subject: Exxon Research Project
@ Columbus & Southern Ohio Electric
Conesville Unit No. 5
Exxon Contract ESC-39
EPA Prime 68-02-2696
CE PSS Project 57278
$NO_x$ Emission Tests

Gentlemen:

Attached please find two (2) copies of the CE Test Report No. 79-10 summarizing the results of the $NO_x$ emission tests performed at the subject unit during 1979.

These tests were performed by Exxon Research and Engineering Co., with an observer furnished by CE, as part of their EPA Contract No. 68-02-2696, titled, "Long Term Corrosion Tests of Optimized Utility Boiler Combustion Modifications".

Test results indicate that at full load and normal plant operating conditions (0% overfire air damper opening, 27% excess air) $NO_x$ emission is .595 LB/Million BTU fired. $NO_x$ emission is reduced to .363 LB/Million BTU with 100% overfire air damper opening and 17% excess air.

Should any questions exist with the enclosed report, please forward such to the undersigned, for transmittal and resolution by the CE Field Testing and Performance Results group. Thank you.

Very truly yours,

COMBUSTION ENGINEERING, INC.

JLHenderson

Joseph L. Henderson
Project Administrator
C-E Power Systems Services

JLH:dg
Enclosures
cc: C. P. Moser - CE Sales Cinncinatti, Ohio

## INTRODUCTION

As part of an Exxon Research and Engineering test program to measure the influence of low $NO_x$ emission combustion modifications on waterwall tube fireside corrosion, a series of emission tests were run on Columbus and Southern Ohio Electric's Conesville Station Unit #5 between January 12, 1979 and February 14, 1979. The purpose of these tests was to characterize the relationship between $NO_x$ emissions and unit operating parameters as the initial phase of the four phase EPA Contract No. 68-02-2696.

The testing was performed by Exxon with an observer furnished by CE. This report contains the emissions and board data taken by Exxon, and calculated windbox airflow distributions based on windbox damper positions.

Phase two of the contract consists of 2-3 day tests at low $NO_x$ firing conditions to assess operating problems such as slagging or steam temperature control. Phase three will be four 300 hour tests using corrosion probes to measure corrosion rates under baseline and low $NO_x$ firing conditions. Phase four will be a long term (12-24 months) test using replaceable wall tube sections and ultrasonic wall thickness measurements in addition to corrosion probes to quantify fireside corrosion rates under low $NO_x$ firing.

Phases two through four will begin after the installation of furnace wall gas taps, observation doors for corrosion probe installations and replaceable wall tube sections. Currently the next outage which would allow this work on Unit #5 is scheduled for Fall, 1979.

## UNIT DESCRIPTION

Conesville #5 is a controlled circulation, radiant, reheat, balanced draft boiler firing mid-western bituminous coal through 5 elevations of tilting tangential fuel nozzles. Two elevations of overfire air (OFA) nozzles are available for $NO_x$ emission reduction. Maximum continuous rating is 3,131,619 LB/HR superheat steam flow at 1005°F/2620 PSIG and 2,767,764 LB/HR reheat steam flow at 1005°F/601 PSIG. Control load is 1,416,022 LB/HR reheat steam flow and 1,277,691 LB/HR reheat steam flow.

The Conesville Unit #5 was selected for testing on the basis of the following criteria:

1. The boiler is of modern design capable of meeting the New Source Performance Standard $NO_x$ requirements of .7 LB/million BTU heat input.
2. The windbox is equipped with OFA ports for $NO_x$ reduction.
3. The fuel fired is a mid-western bituminous of from 2½ to 4½ percent sulfur with approximately 20% iron in the ash.

## TEST OBJECTIVES

The objectives of Phase I of the Test Program are to establish:

1. $NO_x$ emission levels under normal, full load operation
2. Minimum $NO_x$ emission at full load using low $NO_x$ operation.

Additionally, tests were conducted at reduced loads to obtain sufficient data to optimize operation at reduced loads during the long term tests scheduled for phases III and IV.

## CONCLUSIONS

(1) The average $NO_x$ emission at normal (27%) excess air and with minimum overfire air was .595 LB/million BTU fired, within the NSPS of .7 LB/$10^6$ BTU.

(2) At full load, $NO_x$ emission could be reduced by 39%, from .595 LB/$10^6$ BTU to .363 LB/$10^6$ BTU, by the use of 100% overfire air damper opening and low (17%) excess air.

(3) At a reduced load, 60% MCR, opening the overfire air dampers from 5% to 100% reduced $NO_x$ emission by 36% from .470 LB/$10^6$ BTU to .300 LB/$10^6$ BTU. This reduction in $NO_x$ was achieved with no change in excess air.

(4) The effects of varying fuel nozzle tilt and overfire air nozzle tilts on $NO_x$ emissions were small over the range of test conditions.

(5) The use of overfire air and low excess air to reduce $NO_x$ emissions had no adverse effect on unit operation.

## DISCUSSION

Forty-seven emissions tests were performed by Exxon Research and Engineering on Conesville #5 between January 12, 1979 and February 14, 1979. Tests 1, 2 and 4 were preliminary tests to check the test equipment and no results are included in this report. The effects of changing the following parameters on $NO_x$ emissions were investigated: overfire air damper opening, excess air, load, and fuel nozzle and overfire air nozzle tilt.

A summary of operating parameters affecting $NO_x$ and the measured $NO_x$ emission for each test follows. Excluding the economizer outlet oxygen and the $NO_x$ emission values, all data is from plant instrumentation.

Oxygen measurements are presented as averages of samples from the 4 probes in the economizer outlet duct. These averages have not been flow weighted. During some tests, moisture condensed and froze in the sample lines. This ice blockage prevented adequate sample flow for analysis from all four probes. If three of the four probes had adequate sample flow the test was continued and the average of the three unclogged probes is shown.

In addition to the NOx and O2 results shown on Sheet 3, CO levels were recorded for each test. However, CO levels were taken primarily as an aid in setting operating parameters for test conditions and CO levels have not been tabulated in this report. CO levels were below 200 PPM for all test conditions.

$SO_2$ and $SO_3$ were measured during Test 16 by wet chemical methods. The SO2 and SO3 results are considered as preliminary until further data is available to substantiate the single $SO_2$-$SO_3$ test. No $SO_2$-$SO_3$ results are included in this report.

# SUMMARY OF NOX EMISSION RESULTS

| DATE | TEST NO. | MW | MAIN STEAM FLOW $10^3$ LB/HR | NHI/PA $10^6$BTU/HR-FT$^2$ | FUEL ELEV. IN SERV.[1] | $O_2$ % | FUEL NOZZLE TILT DEG. | AIR PRE-HEAT °F | DAMPERS FUEL/AUX. AIR % OPEN | OVER-FIRE AIR YES/NO | OVERFIRE AIR DAMPER POSITION % OPEN | OVER-FIRE AIR TILT DEG. | FUEL $N_2$ % | $NO_X$-PPM (ADJ. TO 3% $O_2$) | $NO_X$-LBS/$10^6$BTU FIRED |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1/15/79 | 3 | 406 | 3000 | 1.68 | ALL | 4.4 | 0 | 550* | 92/31 | NO | 5 | 0 | 1.0 | 525 | .710 |
| 1/16/79 | 5 | 404 | 3000 | 1.68 | ALL | 4.8 | 0 | 552* | 87/30 | NO | 5 | 0 | 1.0 | 379 | .512 |
| 1/16/79 | 6 | 403 | 3000 | 1.67 | ALL | 3.2 | 0 | 560* | 87/24 | NO | 5 | 0 | 1.0 | 368 | .498 |
| 1/17/79 | 7 | 405 | 3000 | 1.68 | ALL | 4.2 | 0 | 561* | 84/24 | YES | 50/0** | 0 | 1.0 | 365 | .493 |
| 1/17/79 | 8 | 401 | 2949 | 1.66 | ALL | 2.8 | 0 | 558* | 83/17 | YES | 50/0** | 0 | 1.0 | 268 | .362 |
| 1/19/79 | 9 | 248 | 1754 | 1.03 | ABCD | 6.0 | 0 | 517 | 63/15 | NO | 5 | 0 | 1.0 | 378 | .511 |
| 1/23/79 | 10 | 403 | 2991 | 1.67 | ALL | 3.9 | 0 | 572 | 91/27 | NO | 5 | 0 | 1.0 | 417 | .564 |
| 1/23/79 | 11 | 407 | 3016 | 1.69 | ALL | 3.9 | 0 | 569 | 91/21 | YES | 50 | 0 | 1.0 | 343 | .464 |
| 1/23/79 | 12 | 407 | 3003 | 1.69 | ALL | 2.8 | -2 | 568 | 91/17 | YES | 50 | 0 | 1.0 | 295 | .399 |
| 1/23/79 | 13 | 408 | 3008 | 1.69 | ALL | 2.9 | -3 | 571 | 91/15 | YES | 100 | 0 | 1.0 | 281 | .380 |
| 1/23/79 | 14 | 408 | 3010 | 1.69 | ALL | 4.0 | -3 | 573 | 91/19 | YES | 100 | 0 | 1.0 | 332 | .449 |
| 1/23/79 | 15 | 409 | 3030 | 1.70 | ALL | 4.5 | -3 | 573 | 91/30 | NO | 0 | 0 | 1.0 | 468 | .633 |
| 1/24/79 | 16 | 401 | 2956 | 1.68 | ALL | 4.4 | 0 | 574 | 87/22 | YES | 50 | +10 | 1.0 | 355 | .480 |
| 1/24/79 | 17 | 368 | 2701 | 1.53 | ABCD | 4.4 | 0 | 555 | 98/19 | YES | 50 | +10 | 1.0 | 288 | .389 |
| 1/24/79 | 18 | 370 | 2701 | 1.53 | ABCD | 2.8 | 0 | 555 | 98/13 | YES | 50 | +10 | 1.0 | 224 | .303 |
| 1/[illegible]/79 | 19 | 402 | 2950 | 1.67 | ALL | 3.0 | 0 | 576 | 98/15 | YES | 50 | +10 | 1.0 | 276 | .373 |
| 1/[illegible]9 | 20 | 402 | 2954 | 1.67 | ALL | 2.4 | 0 | 574 | 98/17 | YES | 50/0** | +10 | 1.0 | 334 | .451 |
| 1/25/79 | 21 | 402 | 2954 | 1.67 | ALL | 2.6 | 0 | 573 | 97/18 | YES | 75/0** | +10 | 1.0 | 325 | .439 |
| 1/25/79 | 22 | 404 | 2975 | 1.68 | ALL | 3.1 | 0 | 576 | 97/14 | YES | 75 | +10 | 1.0 | 263 | .356 |
| 1/25/79 | 23 | 403 | 2976 | 1.67 | ALL | 3.3 | 0 | --- | 97/17 | YES | 100 | +10 | 1.0 | 266 | .360 |
| 1/25/79 | 25 | 402 | 2955 | 1.67 | ALL | 2.8 | 0 | --- | 96/17 | YES | 0/100** | +10 | 1.0 | 316 | .427 |
| 1/25/79 | 25 | 403 | 2959 | 1.67 | ALL | 3.1 | 0 | --- | 96/18 | YES | 100/0** | +10 | 1.0 | 330 | .446 |
| 1/25/79 | 26 | 404 | 2962 | 1.68 | ALL | 3.6 | 0 | 576 | 93/17 | YES | 75 | 0 | 1.0 | 260 | .352 |
| 1/30/79 | 27 | 323 | 2340 | 1.34 | ABDE | 5.5 | +3 | 544 | 99/23 | NO | 5 | 0 | .7 | 418 | .574 |
| 1/30/79 | 28 | 321 | 2327 | 1.33 | ABDE | 1.8 | +3 | 540 | 99/14 | NO | 5 | 0 | .7 | 289 | .397 |
| 1/30/79 | 29 | 325 | 2338 | 1.35 | ABDE | 5.5 | +3 | 547 | 99/17 | YES | 50 | 0 | .7 | 342 | .470 |
| 1/30/79 | 30 | 327 | 2370 | 1.36 | ABDE | 2.9 | +3 | 542 | 99/15 | YES | 50 | 0 | .7 | 241 | .331 |
| 1/31/79 | 31 | 303 | 2222 | 1.26 | ABDE | 5.1 | 0 | 528 | 96/13 | YES | 100 | 0 | .7 | 268 | .368 |
| 1/31/79 | 32 | 307 | 2228 | 1.27 | ABDE | 4.3 | 0 | 526 | 96/13 | YES | 100 | 0 | .7 | 226 | .310 |
| 2/01/79 | 33 | 341 | 2521 | 1.41 | ABDE | 3.7 | 0 | 545 | 99/15 | YES | 75 | 0 | .7 | 211 | .290 |
| 2/01/79 | 34 | 342 | 2522 | 1.42 | ABDE | 4.3 | 0 | 547 | 99/13 | YES | 75 | +10 | .7 | 184 | .253 |
| 2/01/79 | 35 | 343 | 2525 | 1.42 | ABDE | 4.5 | 0 | 543 | 99/13 | YES | 75 | -10 | .7 | 198 | .272 |
| 2/06/79 | 36 | 255 | 1782 | 1.06 | ABD | 6.0 | +7 | 516 | 99/16 | NO | 5 | 0 | .6 | 340 | .468 |
| 2/06/79 | 37 | 255 | 1792 | 1.06 | ABD | 5.6 | +10 | 515 | 99/13 | YES | 50 | 10 | .6 | 268 | .369 |
| 2/06/79 | 38 | 254 | 1799 | 1.05 | ABD | 5.5 | +10 | 515 | 99/13 | YES | 75 | 10 | .6 | 234 | .322 |
| 2/06/79 | 39 | 253 | 1794 | 1.05 | ABD | 5.9 | +10 | 513 | 99/13 | YES | 100 | 10 | .6 | 218 | .300 |
| 2/06/79 | 40 | 253 | 1780 | 1.05 | ABD | 4.6 | +10 | 514 | 99/14 | NO | 5 | 10 | .6 | 343 | .472 |
| 2/07/79 | 41 | 306 | 2159 | 1.27 | ABDE | 4.6 | +2 | 542 | 80/15 | NO | 5 | 10 | .6 | 311 | .428 |
| 2/07/79 | 42 | 307 | 2114 | 1.27 | ABDE | 4.6 | +2 | 545 | 80/15 | YES | 50 | 10 | .6 | 222 | .305 |
| 2/07/79 | 43 | 309 | 2174 | 1.28 | ABDE | 3.8 | +2 | 538 | 79/14 | YES | 100 | 10 | .6 | 173 | .238 |
| 2/12/79 | 44 | 353 | 2537 | 1.46 | ABDE | 3.8 | 0 | 547 | 99/14 | YES | 100 | 10 | .6 | 199 | .274 |
| 2/12/79 | 45 | 353 | 2529 | 1.46 | ABDE | 3.8 | 0 | 547 | 99/14 | YES | 100 | 0 | .6 | 227 | .312 |
| 2/12/79 | 46 | 355 | 2530 | 1.47 | ABDE | 3.6 | 0 | 550 | 99/14 | YES | 100 | -10 | .6 | 244 | .336 |
| 2/14/79 | 47 | 147 | 1012 | 0.61 | DE | 9.8 | -3 | 484 | 57/14 | NO | 0 | -10 | .6 | 424 | .583 |

[1] E[illegible]TIONS WERE E, D, C, B, A FROM TOP TO BOTTOM

*SECONDARY AIR LEAVING AIR HEATER TEMPERATURE, OTHERWISE WEIGHTED AVERAGE OF PRIMARY AND SECONDARY AIR TEMPERATURES

**IF GG AND FF OVERFIRE AIR DAMPERS WERE NOT IN THE SAME POSITION, POSITIONS INDICATED ARE GG/FF

The full range of fuel nozzle tilts is not used at Conesville #5, and this has allowed slag to accumulate between the nozzles. The range of fuel nozzle tilts available during testing was limited from -3° to +10°. Slag accumulation also limited the range of overfire air nozzle tilts from -10° to +10°.

The fuel air damper position is reported as the average of the elevations in service. The auxiliary air damper position reported is the position of all auxiliary air dampers except the "AA" and the warm-up oil gun elevations. These lower two elevations were biased to open more than the other auxiliary air dampers to increase the brightness of the fire in the lower furnace.

Because of previous reports of a dark appearance in the lower furnace, frequent lower furnace observations were made during testing. The lower furnace appearance was bright for all tests except tests 33, 34, 35 (340 MW) and tests 41, 42, 43 (307 MW). During these tests the hopper was dimly illuminated with individual tube outlines being distinguishable only during occasional light flashes. Raising excess air or decreasing the amount of overfire air increased the brightness in the hopper.

Board and computer data was taken to characterize unit operating conditions and follows.

A fuel sample was taken by the plant's automatic sampling system once during each day of testing. These samples were taken from the coal conveying system before the silos. An ultimate analysis was performed by KDL on the samples dated 1/25, 1/31, and 2/8. The results follow.

Overfire air was the most effective means of $NO_x$ reduction on Conesville #5. $NO_x$ emission is plotted against overfire air damper opening for 14 full load tests and for 11 reduced load tests. Increasing overfire air from minimum to 100% damper opening reduced $NO_x$ by approximately .16 LB/$10^6$BTU, independent of load or excess air. Increasing the overfire air damper opening from 5% to 50% produced a larger reduction in $NO_x$ than in-

# BOARD & COMPUTER DATA

| **TEST NO.** | | **3** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Load | MW | 406 | 404 | 403 | 405 | 401 | 248 | 403 | 407 | 407 | 408 | 408 |
| Date | 1979 | 1/15 | 1/16 | 1/16 | 1/17 | 1/17 | 1/19 | 1/23 | 1/23 | 1/23 | 1/23 | 1/23 |
| Time | HRS | 1130 | 1100 | 1600 | 1500 | 1640 | 1345 | 1045 | 1245 | 1400 | 1445 | 1530 |
| **CONTROL VARIABLES** | | | | | | | | | | | | |
| Oxygen Econ. Out. Probe 1 | % | -- | -- | -- | -- | -- | 5.5 | 3.6 | 3.7 | 2.5 | 3.0 | 3.8 |
| 2 | % | 4.2 | 3.9 | 2.5 | 4.1 | 2.5 | 5.4 | 4.1 | 4.1 | 3.0 | 3.1 | 4.0 |
| 3 | % | -- | -- | -- | -- | -- | 4.6 | 3.1 | 3.3 | 2.8 | 2.4 | 3.5 |
| Avg. | % | 4.2 | 3.9 | 2.5 | 4.1 | 2.5 | 5.2 | 3.6 | 3.7 | 2.8 | 2.8 | 3.8 |
| OFA Damper Pos. | % | 5 | 5 | 5 | 50/5* | 50/5* | 5 | 5 | 50 | 50 | 100 | 100 |
| OFA Nozzle Tilt | DEG | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Fuel Nozzle Tilt | DEG | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -2 | -3 | -3 |
| Elev. in Serv. (E-Top, A-Bot.) | OF 5 | ALL | ALL | ALL | ALL | ALL | ABCD | ALL | ALL | ALL | ALL | ALL |
| Damper Pos. Fuel Air/Aux. Air | %/% | 92/31 | 87/30 | 87/24 | 84/24 | 83/17 | 63/15 | 91/27 | 91/21 | 91/17 | 91/15 | 91/19 |
| Windbox - Furn. Diff. | "WG | 6 | 5 | 5 | 6 | 5 | 3.2 | 6.2 | 5.3 | 6.1 | 5.5 | 6.4 |
| **FLOWS - STEAM & WATER** | | | | | | | | | | | | |
| Feedwater | $10^3$LB/HR | 3010** | 3010** | 2975** | 2975** | 2975** | 1893 | 3076 | 3091 | 3077 | 3091 | 3098 |
| SH Spray | $10^3$LB/HR | 290 | 248 | 250 | 300 | 212 | 85 | 223 | 175 | 205 | 223 | 242 |
| Main Steam | $10^3$LB/HR | 3000 | 3000 | 3000 | 3000 | 3000 | 1750 | 3050 | 3070 | 3050 | 3080 | 3080 |
| RH Spray | GPH | 0 | 0 | 9000 | 3900 | 4000 | 0 | 0 | 0 | 0 | 0 | 0 |
| Condensate | $10^3$LB/HR | -- | -- | -- | -- | -- | -- | -- | 2459 | 2469 | 2497 | 2510 |
| **.OWS - AIR & GAS** | | | | | | | | | | | | |
| Total Air | % | 83 | 80 | 75 | 83 | 75 | 50 | 83 | 82 | 78 | 78 | 83 |
| Secondary Air to Windbox L | % | -- | -- | -- | -- | -- | 45 | 65 | 64 | 61 | 62 | 66 |
| R | % | -- | -- | -- | -- | -- | 37 | 60 | 60 | 55 | 55 | 61 |
| Primary Air to Mills E | % | -- | -- | -- | -- | -- | 34 | 80 | 80 | 81 | 80 | 80 |
| D | % | -- | -- | -- | -- | -- | 78 | 80 | 79 | 80 | 80 | 80 |
| C | % | -- | -- | -- | -- | -- | 79 | 80 | 80 | 80 | 80 | 80 |
| B | % | -- | -- | -- | -- | -- | 81 | 80 | 80 | 80 | 81 | 81 |
| A | % | -- | -- | -- | -- | -- | 80 | 81 | 79 | 80 | 80 | 80 |
| **PRESSURES - STEAM & WATER** | | | | | | | | | | | | |
| Drum | PSIG | -- | -- | -- | -- | -- | -- | -- | -- | 2649 | 2637 | 2637 |
| Superheater Outlet | PSIG | -- | -- | -- | -- | -- | -- | -- | -- | 2456 | 2450 | 2445 |
| Throttle | PSIG | 2404 | 2407 | 2412 | 2402 | 2393 | 2350 | 2395 | 2406 | 2403 | 2404 | 2406 |
| Turbine 1st Stage | PSIG | -- | -- | -- | -- | 1750 | 1054 | 1759 | 1777 | 1773 | 1773 | 1775 |
| Cold Reheat | PSIG | -- | -- | -- | -- | -- | 352 | 597 | 601 | 602 | 603 | 603 |
| Hot Reheat | PSIG | -- | 547 | 554 | 554 | 550 | 320 | 547 | 551 | 551 | 553 | 553 |
| **PRESSURES - AIR & GAS** | | | | | | | | | | | | |
| Atmospheric | PSIA | 14.7 | 14.7 | 14.6 | 14.4 | 14.4 | 14.54 | 14.43 | 14.37 | 14.35 | 14.34 | 14.32 |
| Primary Air AH Inlet | "WG | 37 | 37 | 36 | 36 | 36 | 40 | 35 | 35 | 35 | 35 | 35 |
| AH Outlet | "WG | 35 | 32 | 31 | 34 | 35 | 33 | 31 | 32 | 31 | 32 | 31 |
| FD Fan Outlet | "WG | 17 | 14 | 15 | 19 | 12 | 10 | 14 | 16 | 13 | 13 | 17 |
| Secondary Air AH Inlet | "WG | 12 | 14 | 13 | 15 | 10 | 8 | 11 | 13 | 11 | 12 | 12 |
| AH Outlet | "WG | 8 | 7 | 7 | 8 | 7 | 3 | 6 | 6 | 7 | 6 | 6 |
| Windbox | "WG | 5 | 4 | 5 | 5 | 5 | 3 | 4 | 4.3 | 4.1 | 4.5 | 4.4 |
| Furnace | "WG | -1 | -1 | 0 | -1 | -1 | 0 | -2 | -1 | -2 | -1 | -2 |
| Flue Gas After RH Pendant | "WG | -1 | -1 | -2 | -1 | -2 | -.5 | -2 | -1 | -.7 | -1.2 | -1.4 |
| After Horiz. SH | "WG | -3 | -2 | -3 | -2 | -3 | -1 | -3 | -3 | -3 | -3 | -3 |
| At AH Inlet | "WG | -7 | -7.5 | -6.5 | -7.5 | -5 | -7.6 | -7.9 | -7.8 | -6.3 | -6.9 | -8.0 |
| At AH Outlet | "WG | -13 | -14 | -12 | -15.5 | -12.5 | -8.9 | -13.3 | -13.4 | -12.2 | -11.4 | -14.0 |
| At Precip. Outlet | "WG | -15 | -15 | -14 | -15 | -15 | -9.1 | -14.6 | -14.7 | -13.6 | -13.1 | -15.4 |
| At ID Fan Outlet | "WG | 3 | 7 | 6 | 8.5 | 6 | 0 | 4.4 | 4.5 | 4.1 | 4.0 | 5.2 |
| At Scrubber Outlet | "WG | -3 | -3 | -4 | -- | -4 | -4 | -3 | -3 | -3 | -3 | -3 |

* Positions indicated are GG OFA Damper Position/FF OFA Damper Position.

** These feedwater flows were read as percentages of MCR flow but have been expressed as absolute flows by assuming 100 percent feedwater flow = 3500 X $10^3$LB/HR.

# BOARD & COMPUTER DATA

| TEST NO. | | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Load | MW | 409 | 401 | 368 | 370 | 402 | 402 | 402 | 404 | 403 | 402 | 403 |
| Date | 1979 | 1/23 | 1/24 | 1/24 | 1/24 | 1/25 | 1/25 | 1/25 | 1/25 | 1/25 | 1/25 | 1/25 |
| Time | HRS | 1600 | 1015 | 1345 | 1530 | 0900 | 0930 | 1000 | 1030 | 1300 | 1330 | 1400 |
| **CONTROL VARIABLES** | | | | | | | | | | | | |
| Oxygen Econ. Out. Probe 1 | % | 3.9 | 3.8 | 4.1 | 2.5 | 2.6 | 2.8 | 2.5 | 3.4 | -- | -- | -- |
| 2 | % | 4.1 | 4.0 | 4.2 | 2.6 | 2.5 | 2.9 | 2.9 | 2.8 | 2.5 | 2.4 | 2.6 |
| 3 | % | 3.7 | 4.1 | 3.2 | 2.1 | 2.1 | 2.1 | 1.8 | 2.1 | -- | -- | -- |
| Avg. | % | 3.9 | 4.0 | 3.8 | 2.4 | 2.4 | 2.6 | 2.4 | 2.8 | 2.5 | 2.4 | 2.6 |
| OFA Damper Pos. | % | 0 | 50 | 50 | 50 | 50 | 50/0* | 75/0* | 75 | 100 | 0/100* | 100/0* |
| OFA Nozzle Tilt | DEG | 0 | +10 | +10 | +10 | +10 | +10 | +10 | +10 | +10 | +10 | +10 |
| Fuel Nozzle Tilt | DEG | -3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Elev. In Serv. (E-Top, A-Bot.) | OF 5 | ALL | ALL | ABCD | ABCD | ALL | ALL | ALL | ALL | ALL | ALL | ALL |
| Damper Pos. Fuel Air/Aux. Air | %/% | 91/30 | 87/22 | 98/19 | 98/13 | 98/15 | 98/17 | 97/18 | 97/14 | 97/17 | 96/17 | 96/18 |
| Windbox - Furn. Diff. | "WG | 5.8 | 6.0 | 6.1 | 5.1 | 7.1 | 6.4 | 6.3 | 5.9 | 4.0 | 4.5 | 4.3 |
| **FLOWS - STEAM & WATER** | | | | | | | | | | | | |
| Feedwater | $10^3$LB/HR | 3020 | 3064 | 2794 | 2808 | 3044 | 3048 | 3060 | 3043 | 2940** | 2940** | 2940** |
| SH Spray | $10^3$LB/HR | 239 | 227 | 153 | 182 | 297 | 287 | 274 | 285 | ≫300 | ≫300 | ≫300 |
| Main Steam | $10^3$LB/HR | 3100 | 3000 | 2750 | 2750 | 3000 | 3000 | 3000 | 3050 | 3030 | 3000 | 3000 |
| RH Spray | GPH | 0 | 0 | 0 | 0 | 4800 | 4800 | 4800 | 4800 | 6300 | 6300 | 6300 |
| Condensate | $10^3$LB/HR | 2519 | 2488 | 2264 | 2252 | 2479 | 2498 | 2494 | 2473 | -- | -- | -- |
| **FLOWS - AIR & GAS** | | | | | | | | | | | | |
| Total Air | % | 84 | 83 | 73 | 67 | 76 | 76 | 77 | 76 | 76 | 76 | 77 |
| Secondary Air to Windbox L | % | 66 | 61 | 61 | 56 | 61 | 61 | 60 | 60 | -- | -- | -- |
| R | % | 60 | 61 | 54 | 47 | 51 | 53 | 51 | 50 | -- | -- | -- |
| Primary Air to Mills E | % | 80 | 81 | OFF | OFF | 80 | 81 | 82 | 81 | -- | -- | -- |
| D | % | 80 | 80 | 80 | 80 | 81 | 81 | 80 | 81 | -- | -- | -- |
| C | % | 80 | 80 | 80 | 81 | 80 | 81 | 80 | 80 | -- | -- | -- |
| B | % | 80 | 82 | 80 | 80 | 80 | 81 | 81 | 81 | -- | -- | -- |
| A | % | 80 | 81 | 80 | 80 | 80 | 81 | 81 | 81 | -- | -- | -- |
| **PRESSURES - STEAM & WATER** | | | | | | | | | | | | |
| Drum | PSIG | 2651 | 2627 | 2603 | 2594 | 2627 | 2639 | 2635 | 2631 | 2600 | 2600 | 2600 |
| Superheater Outlet | PSIG | 2447 | 2441 | 2449 | 2436 | 2447 | 2456 | 2459 | 2455 | -- | -- | -- |
| Throttle | PSIG | 2400 | 2399 | 2411 | 2414 | 2419 | 2411 | 2429 | 2406 | 2417 | 2406 | 2418 |
| Turbine 1st Stage | PSIG | 1776 | 1747 | 1591 | 1591 | 1740 | 1744 | 1744 | 1739 | 1753 | 1746 | 1750 |
| Cold Reheat | PSIG | 603 | 585 | 540 | 540 | 599 | 598 | 600 | 596 | -- | -- | -- |
| Hot Reheat | PSIG | 552 | 545 | 495 | 494 | 549 | 548 | 551 | 546 | -- | -- | -- |
| **PRESSURES - AIR & GAS** | | | | | | | | | | | | |
| Atmospheric | PSIA | 14.33 | 14.06 | 14.04 | 14.07 | 14.30 | 14.30 | 14.31 | 14.33 | -- | -- | -- |
| Primary Air AH Inlet | "WG | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 36 | 36 | 36 |
| AH Outlet | "WG | 31 | 32 | 32 | 33 | 31 | 31 | 31 | 31 | 32 | 34 | 32 |
| FD Fan Outlet | "WG | 17 | 15 | 13 | 13 | 14 | 14 | 14 | 13 | 14 | 13 | 14 |
| Secondary Air AH Inlet | "WG | 12 | 13 | 11 | 10 | 10 | 10 | 9 | 11 | 11 | 10 | 12 |
| AH Outlet | "WG | 6 | 7 | 5 | 5 | 6 | 6 | 5 | 5 | 7 | 6 | 7 |
| Windbox | "WG | 4.8 | 5.0 | 4.1 | 4.1 | 5.1 | 4.4 | 4.3 | 3.9 | 3.5 | 4 | 4.8 |
| Furnace | "WG | -1 | -1 | -2 | -1 | -2 | -2 | -2 | -2 | -.5 | -.5 | -.5 |
| Flue Gas After RH Pendant | "WG | -1.0 | -.8 | -.7 | -1.1 | -.5 | -1.5 | -1.3 | -1.4 | -1 | 0 | -1 |
| After Horiz. SH | "WG | -3 | -2 | -2 | -2 | -3 | -3 | -3 | -3 | -3 | -2 | -3 |
| At AH Inlet | "WG | -6.9 | -7.2 | -5.8 | -6.1 | -7.1 | -6.6 | -6.6 | -6.9 | -7 | -7 | -7 |
| At AH Outlet | "WG | -12.9 | -13.3 | -10.6 | -9.7 | -11.3 | -11.8 | -11.3 | -12.0 | -12 | -12 | -11 |
| At Precip. Outlet | "WG | -14.8 | -14.6 | -12.3 | -11.4 | -12.2 | -13.3 | -12.7 | -13.7 | -13 | -13.5 | -13 |
| At ID Fan Outlet | "WG | 4.7 | 4.3 | 2.9 | 2.4 | 1.6 | 2.2 | 2.1 | 1.4 | 1 | 0 | .5 |
| At Scrubber Outlet | "WG | -3 | -3 | -4 | -4 | -3 | -4 | -3 | -4 | -4 | -3.5 | -3.5 |

* Positions indicated are GG OFA Damper Position/FF OFA Damper Position.

**These feedwater flows were read as percentages of MCR flow but have been expressed as absolute flows by assuming 100 percent feedwater flow = 3500 X $10^3$LB/HR.

# BOARD & COMPUTER DATA

| TEST NO. | | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Load | MW | 404 | 323 | 321 | 325 | 327 | 303 | 307 | 341 | 342 | 343 | 255 |
| Date | 1979 | 1/25 | 1/30 | 1/30 | 1/30 | 1/30 | 1/31 | 1/31 | 2/1 | 2/1 | 2/1 | 2/6 |
| Time | HRS | 1430 | 1045 | 1145 | 1245 | 1330 | 1400 | 1500 | 1000 | 1100 | 1345 | 0005 |
| **CONTROL VARIABLES** | | | | | | | | | | | | |
| Oxygen Econ. Out. Probe 1 | % | 2.8 | 5.1 | 1.0 | 5.0 | 1.7 | 3.8 | 3.2 | 1.9 | 2.9 | 2.4 | 5.3 |
| 2 | % | 2.7 | 5.5 | 1.9 | 5.3 | 2.6 | 4.4 | 3.6 | 2.6 | 2.8 | 2.6 | 5.5 |
| 3 | % | 2.0 | 4.5 | 1.6 | 5.1 | 2.6 | 3.9 | 3.3 | 2.8 | 2.3 | 2.9 | 5.2 |
| Avg. | % | 2.5 | 5.0 | 1.5 | 5.1 | 2.3 | 4.0 | 3.4 | 2.4 | 2.7 | 2.6 | 5.3 |
| OFA Damper Pos. | % | 75 | 5 | 5 | 50 | 50 | 100 | 100 | 75 | 75 | 75 | 5 |
| OFA Nozzle Tilt | DEG | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | +10 | -10 | 0 |
| Fuel Nozzle Tilt | DEG | 0 | +3 | +3 | +3 | +3 | 0 | 0 | 0 | 0 | 0 | +7 |
| Elev. In Serv. (E-Top, A-Bot.) | OF 5 | ALL | ABDE | ABDE | ABDE | ABDE | ABDE | ABDE | ABDE | ABDE | ABDE | ABD |
| Damper Pos. Fuel Air/Aux. Air | %/% | 93/17 | 99/23 | 99/14 | 99/17 | 99/15 | 96/13 | 96/13 | 99/15 | 99/13 | 99/13 | 99/16 |
| Windbox - Furn. Diff. | ″WG | 6.7 | 5.4 | 4.6 | 5.3 | 2.8 | 3.1 | 3.7 | 5.0 | 3.9 | 3.5 | 6.5 |
| **FLOWS - STEAM & WATER** | | | | | | | | | | | | |
| Feedwater | $10^3$LB/HR | 3062 | 2467 | 2451 | 2467 | 2525 | 2384 | 2346 | 2656 | 2677 | 2712 | 1943 |
| SH Spray | $10^3$LB/HR | 300 | 156 | 112 | 185 | 120 | 93 | 95 | 144 | 163 | 162 | 96 |
| Steam | $10^3$LB/HR | 3000 | 2350 | 2350 | 2350 | 2400 | 2250 | 2250 | 2550 | 2550 | 2550 | -- |
| Spray | GPM | 6500 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Condensate | $10^3$LB/HR | 2480 | 1962 | 1971 | 1953 | 1991 | 2036 | 2009 | 2236 | 2249 | 2295 | 1577 |
| **FLOWS - AIR & GAS** | | | | | | | | | | | | |
| Total Air | % | 76 | 71 | 55 | 71 | 58 | 64 | 60 | 64 | 64 | 63 | -- |
| Secondary Air to Windbox L | % | 60 | 60 | 47 | 60 | 49 | 54 | 51 | 56 | 55 | 56 | 49 |
| R | % | 51 | 50 | 33 | 50 | 37 | 42 | 39 | 43 | 42 | 44 | 36 |
| Primary Air to Mills E | % | 79 | 92 | 94 | 94 | 94 | 80 | 81 | 82 | 95 | 95 | OFF |
| D | % | 80 | 79 | 80 | 81 | 80 | 81 | 81 | 80 | 80 | 81 | 80 |
| C | % | 80 | OFF | OFF | OFF | OFF | OFF | OFF | OFF | OFF | OFF | OFF |
| B | % | 81 | 80 | 80 | 81 | 80 | 81 | 81 | 80 | 80 | 80 | 80 |
| A | % | 81 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 |
| **PRESSURES - STEAM & WATER** | | | | | | | | | | | | |
| Drum | PSIG | 2649 | 2538 | 2511 | 2528 | 2567 | 2515 | 2519 | 2564 | 2561 | 2564 | 2459 |
| Superheater Outlet | PSIG | 2474 | 2429 | 2405 | 2428 | 2391 | 2422 | 2414 | 2439 | 2437 | 2438 | 2426 |
| Throttle | PSIG | 2392 | 2407 | 2373 | 2390 | 2388 | 2395 | 2395 | 2408 | 2413 | 2413 | 2387 |
| Turbine 1st Stage | PSIG | 1754 | 1398 | 1382 | 1395 | 1403 | 1316 | 1323 | 1495 | 1496 | 1499 | 1069 |
| Cold Reheat | PSIG | 595 | 470 | 465 | 468 | 465 | 440 | 440 | 498 | 501 | 502 | 361 |
| Hot Reheat | PSIG | 546 | 429 | 424 | 428 | 425 | 402 | 402 | 456 | 458 | 460 | 328 |
| **PRESSURES - AIR & GAS** | | | | | | | | | | | | |
| Atmospheric | PSIA | 14.35 | 14.51 | 14.51 | 14.49 | 14.48 | 14.34 | 14.36 | 14.54 | 14.53 | 14.53 | 14.63 |
| Primary Air AH Inlet | ″WG | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 34 | 34 |
| AH Outlet | ″WG | 32 | 31 | 33 | 33 | 33 | 33 | 33 | 33 | 33 | 32 | 33 |
| FD Fan Outlet | ″WG | 14 | 14 | 8 | 14 | 8 | 9 | 8 | 10 | 8 | 9 | 10 |
| Secondary Air AH Inlet | ″WG | 10 | 10 | 6 | 10 | 6 | 7 | 4 | 7 | 7 | 7 | 8 |
| AH Outlet | ″WG | 6 | 6 | 3 | 6 | 3 | 3 | 2 | 4 | 3 | 4 | 5 |
| Windbox | ″WG | 4.7 | 4.4 | 2.6 | 4.3 | 1.8 | 2.1 | 1.7 | 3.0 | 1.9 | 2.5 | 4.5 |
| Furnace | ″WG | -2 | -1 | -2 | -1 | -1 | -1 | -2 | -2 | -2 | -1 | -2 |
| Flue Gas After RH Pendant | ″WG | -1.4 | -1.3 | -1.0 | -.3 | -1.0 | -1.0 | -.8 | -.8 | -.5 | -1.3 | -.7 |
| After Horiz. SH | ″WG | -3 | -2.2 | -2.0 | -1.9 | -2.1 | -2.2 | -1.7 | -2.4 | -2.5 | -2.7 | -2.1 |
| At AH Inlet | ″WG | -7.3 | -5.9 | -4.3 | -6.1 | -4.7 | -5.3 | -4.9 | -4.8 | -4.9 | -5.7 | -4.9 |
| At AH Outlet | ″WG | -11.8 | -9.9 | -7.3 | -10.6 | -7.9 | -8.6 | -7.4 | -9.1 | -8.9 | -8.9 | -7.6 |
| At Precip. Outlet | ″WG | -12.9 | -11.6 | -8.8 | -11.7 | -9.4 | -9.4 | -8.8 | -10.5 | -10.2 | -10.2 | -8.7 |
| At ID Fan Outlet | ″WG | 1.5 | 1.3 | 0 | 2.0 | 0 | .6 | .2 | 0 | 0 | 0 | 0 |
| At Scrubber Outlet | ″WG | -3 | -4 | -5 | -4 | -4 | -4 | -4 | -4 | -4 | -4 | -4 |

# BOARD & COMPUTER DATA

| TEST NO. |  | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Load | MW | 255 | 254 | 253 | 253 | 306 | 307 | 309 | 353 | 353 | 355 | 147 |
| Date | 1979 | 2/6 | 2/6 | 2/6 | 2/6 | 2/7 | 2/7 | 2/7 | 2/12 | 2/12 | 2/12 | 2/14 |
| Time | HRS | 0100 | 0120 | 0220 | 0320 | 0020 | 0040 | 0255 | 1130 | 1210 | 1300 | 0015 |
| **CONTROL VARIABLES** |  |  |  |  |  |  |  |  |  |  |  |  |
| Oxygen Econ. Out. Probe 1 | % | 5.0 | 4.7 | 4.4 | 5.2 | 3.4 | 3.2 | 3.7 | 3.2 | 3.3 | 3.1 | 9.2 |
| 2 | % | 5.0 | 4.9 | 4.8 | 5.0 | 3.5 | 3.6 | 3.4 | 2.9 | 3.3 | 3.3 | 9.3 |
| 3 | % | 4.7 | 4.5 | 4.0 | 4.1 | 3.6 | 3.5 | 3.1 | 2.5 | 2.6 | 2.8 | 8.5 |
| Avg. | % | 4.9 | 4.7 | 4.4 | 4.8 | 3.5 | 3.4 | 3.4 | 2.9 | 3.1 | 3.1 | 9.0 |
| OFA Damper Pos. | % | 50 | 75 | 100 | 5 | 5 | 50 | 100 | 100 | 100 | 100 | 0 |
| OFA Nozzle Tilt | DEG | +10 | +10 | +10 | +10 | +10 | +10 | +10 | +10 | 0 | -10 | -10 |
| Fuel Nozzle Tilt | DEG | +10 | +10 | +10 | +10 | +2 | +2 | +2 | 0 | 0 | 0 | -3 |
| Elev. In Serv. (E-Top, A-Bot.) | OF 5 | ABD | ABD | ABD | ABD | ABDE | ABDE | ABDE | ABDE | ABDE | ABDE | DE |
| Damper Pos. Fuel Air/Aux. Air | %/% | 99/13 | 99/13 | 99/13 | 99/14 | 80/15 | 80/15 | 79/14 | 99/14 | 99/14 | 99/14 | 57/14 |
| Windbox - Furn. Diff. | "WG | 4.4 | 3.5 | 3.1 | 4.9 | 6.4 | 5.4 | 3.1 | 3.9 | 4.7 | 4.8 | 5.5 |
| **FLOWS - STEAM & WATER** |  |  |  |  |  |  |  |  |  |  |  |  |
| Feedwater | $10^3$LB/HR | 1971 | 1945 | 1965 | 1960 | 2295 | 2341 | 2306 | 2664 | 2668 | 2663 | 1097 |
| SH Spray | $10^3$LB/HR | 135 | 121 | 115 | 111 | 187 | 179 | 212 | 171 | 181 | 207 | 39 |
| Main Steam | $10^3$LB/HR | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| RH Spray | GPM | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Condensate | $10^3$LB/HR | 1583 | 1570 | 1598 | 1571 | 1872 | 1955 | 1907 | 2152 | 2157 | 2150 | 979 |
| **FLOWS - AIR & GAS** |  |  |  |  |  |  |  |  |  |  |  |  |
| Total Air | % | -- | 51 | 50 | -- | -- | -- | -- | -- | -- | -- | 39 |
| Secondary Air to Windbox L | % | 47 | 46 | 45 | 46 | 49 | 45 | 46 | 56 | 57 | 57 | 46 |
| R | % | 35 | 35 | 34 | 31 | 34 | 33 | 35 | 41 | 42 | 42 | 23 |
| Primary Air to Mills E | % | OFF | OFF | OFF | OFF | 81 | 81 | 80 | 80 | 80 | 80 | 79 |
| D | % | 80 | 80 | 80 | 80 | 80 | 80 | 79 | 79 | 79 | 80 | 80 |
| C | % | OFF | OFF | OFF | OFF | OFF | OFF | OFF | OFF | OFF | OFF | OFF |
| B | % | 80 | 80 | 81 | 80 | 80 | 80 | 79 | 80 | 79 | 80 | 26 |
| A | % | 80 | 80 | 80 | 80 | 81 | 84 | 81 | 80 | 80 | 79 | 21 |
| **PRESSURES - STEAM & WATER** |  |  |  |  |  |  |  |  |  |  |  |  |
| Drum | PSIG | 2454 | 2461 | 2444 | 2465 | 2491 | 2545 | 2498 | 2554 | 2558 | 2546 | -- |
| Superheater Outlet | PSIG | 2412 | 2419 | 2405 | 2427 | 2416 | 2472 | 2426 | 2429 | 2434 | 2425 | 2427 |
| Throttle | PSIG | 2382 | 2402 | 2400 | 2386 | 2408 | 2350 | 2412 | 2408 | 2402 | 2406 | 2407 |
| Turbine 1st Stage | PSIG | 1075 | 1079 | 1076 | 1068 | 1290 | 1268 | 1290 | 1524 | 1517 | 1520 | 607 |
| Cold Reheat | PSIG | 363 | 365 | 363 | 361 | 437 | 433 | 435 | 515 | 514 | 516 | 206 |
| Hot Reheat | PSIG | 330 | 332 | 330 | 329 | 399 | 395 | 398 | 471 | 471 | 472 | 185 |
| **PRESSURES - AIR & GAS** |  |  |  |  |  |  |  |  |  |  |  |  |
| Atmospheric | PSIA | 14.64 | 14.64 | 14.65 | 14.65 | 14.46 | 14.44 | 14.43 | 14.46 | 14.47 | 14.44 | 14.54 |
| Primary Air AH Inlet | "WG | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 |
| AH Outlet | "WG | 33 | 33 | 33 | 33 | 33 | 32 | 33 | 33 | 33 | 33 | 34 |
| FD Fan Outlet | "WG | 7 | 7 | 6 | 9 | 11 | 10 | 9 | 11 | 10 | 11 | 8 |
| Secondary Air AH Inlet | "WG | 5 | 5 | 5 | 8 | 8 | 7 | 5 | 7 | 8 | 8 | 6 |
| AH Outlet | "WG | 3 | 2 | 2 | 5 | 5 | 4 | 3 | 4 | 4 | 4 | 5 |
| Windbox | "WG | 2.4 | 1.5 | 1.1 | 3.9 | 4.4 | .4 | 2.1 | 2.9 | 2.7 | 2.8 | 4.5 |
| Furnace | "WG | -2 | -2 | -2 | -1 | -2 | -2 | -1 | -1 | -2 | -2 | -1 |
| Flue Gas After RH Pendant | "WG | -.8 | -.9 | -.8 | -.4 | -1.1 | -1.0 | -.9 | -.7 | -1.1 | -1.0 | -0.1 |
| After Horiz. SH | "WG | -2.1 | -2.0 | -2.1 | -1.8 | -2.1 | -2.2 | -2.2 | -1.8 | -2.4 | -2.4 | -1.3 |
| At AH Inlet | "WG | -4.3 | -4.4 | -3.8 | -3.9 | -5.2 | -5.3 | -5.1 | -5.5 | -5.7 | -5.1 | -3.6 |
| At AH Outlet | "WG | -7.1 | -6.9 | -6.5 | -7.1 | -8.2 | -8.3 | -7.9 | -8.9 | -9.0 | -9.1 | -5.4 |
| At Precip. Outlet | "WG | -7.9 | -8.1 | -7.2 | -7.9 | -9.4 | -9.1 | -9.1 | -10.4 | -10.5 | -10.5 | -6.6 |
| At ID Fan Outlet | "WG | 0 | 0 | 0 | 0 | 0 | .1 | 0 | 0 | .1 | .6 | 0 |
| At Scrubber Outlet | "WG | -4 | -5 | -4 | -4 | -4 | -4 | -4 | -4 | -4 | -4 | -5 |

# BOARD & COMPUTER DATA

| TEST NO. | | 1 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Load | MW | 406 | 404 | 403 | 405 | 401 | 248 | 403 | 407 | 407 | 408 | 408 |
| Date | 1979 | 1/15 | 1/16 | 1/16 | 1/17 | 1/17 | 1/19 | 1/23 | 1/23 | 1/23 | 1/23 | 1/23 |
| Time | HRS | 1130 | 1100 | 1600 | 1500 | 1640 | 1345 | 1045 | 1245 | 1400 | 1445 | 1530 |
| **TEMPERATURES - STEAM & WATER** | | | | | | | | | | | | |
| Feedwater to Economizer | $^{\circ}F$ | -- | -- | -- | -- | -- | -- | -- | -- | 497 | -- | 498 |
| SH Outlet A | $^{\circ}F$ | 993 | 1007 | 1005 | 989 | 1013 | 1004 | 995 | 1001 | 1013 | 1005 | 1006 |
| B | $^{\circ}F$ | 995 | 993 | 987 | 983 | 996 | 991 | 987 | 985 | 990 | 989 | 987 |
| Reheater Outlet A | $^{\circ}F$ | 992 | 1008 | 992 | 1004 | 1005 | 956 | 981 | 995 | 1016 | 1004 | 1010 |
| B | $^{\circ}F$ | 1013 | 1016 | 990 | 1004 | 1003 | 953 | 998 | 993 | 1001 | 1005 | 999 |
| **TEMPERATURES - AIR & GAS** | | | | | | | | | | | | |
| bient Air | $^{\circ}F$ | 7 | 26 | 31 | 39 | 37 | 20 | 29 | 35 | 37 | 39 | 39 |
| bient Air Dew Point | $^{\circ}F$ | -- | -- | -- | 38 | 37 | 17 | 26 | 34 | 36 | 38 | 38 |
| Primary Air AH Inlet | $^{\circ}F$ | -- | -- | -- | -- | -- | 96 | 96 | 97 | 97 | 97 | 97 |
| AH Outlet | $^{\circ}F$ | -- | -- | -- | -- | -- | 545 | 632 | 632 | 625 | 626 | 637 |
| Mill Outlet, Pulverizer 5-E | $^{\circ}F$ | 140 | 159 | 157 | 150 | 145 | OFF | 159 | 153 | 176 | 173 | 173 |
| 5-D | $^{\circ}F$ | 150 | 147 | 146 | 145 | 150 | 140 | 148 | 151 | 136 | 131 | 130 |
| 5-C | $^{\circ}F$ | 160 | 150 | 171 | 150 | 150 | 168 | 174 | 172 | 173 | 172 | 173 |
| 5-B | $^{\circ}F$ | 145 | 146 | 140 | 140 | 140 | 139 | 143 | 144 | 144 | 144 | 141 |
| 5-A | $^{\circ}F$ | 130 | 128 | 127 | 130 | 130 | 121 | 125 | 128 | 128 | 129 | 129 |
| Secondary Air AH Inlet | $^{\circ}F$ | 97 | 101 | 107 | 104 | 106 | 158 | 120 | 98 | 100 | 102 | 100 |
| AH Outlet | $^{\circ}F$ | 550 | 552 | 560 | 561 | 558 | 510 | 557 | 554 | 554 | 558 | 559 |
| Flue Gas Leaving Economizer | $^{\circ}F$ | -- | -- | -- | 752 | 734 | 600 | 739 | 755 | 752 | 755 | 772 |
| Flue Gas Entering AH | $^{\circ}F$ | 689 | 685 | 675 | 694 | 675 | 586 | 688 | 683 | 681 | 682 | 697 |
| Flue Gas Leaving AH | $^{\circ}F$ | 309 | 313 | 317 | 318 | 315 | 311 | 321 | 311 | 310 | 311 | 313 |
| **MISCELLANEOUS** | | | | | | | | | | | | |
| Coal Feeder Rates Total | % | 82 | 78 | 78 | 78 | 76 | 58 | 80 | 80 | 80 | 80 | 79 |
| Coal Feeder Rates Feeder 5-E | $10^3$LB/HR | 61 | 54 | 54 | 48 | 47 | -- | 63 | 64 | 64 | 64 | 64 |
| 5-D | $10^3$LB/HR | 75 | 78 | 77 | 78 | 80 | 54 | 71 | 80 | 77 | 77 | 79 |
| 5-C | $10^3$LB/HR | 69 | 66 | 65 | 64 | 65 | 58 | 65 | 65 | 65 | 65 | 65 |
| 5-B | $10^3$LB/HR | 79 | 80 | 80 | 84 | 81 | 72 | 83 | 79 | 82 | 78 | 80 |
| 5-A | $10^3$LB/HR | 77 | 77 | 79 | 78 | 80 | 43 | 80 | 75 | 77 | 75 | 76 |
| Windbox Damper Pos. OFA GG | % | 5 | 5 | 5 | 5 | 50 | 5 | 5 | 50 | 50 | 100 | 100 |
| OFA FF | % | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 50 | 50 | 100 | 100 |
| Fuel Air E | % | 73 | 56 | 55 | 38 | 39 | 0 | 75 | 77 | 77 | 77 | 77 |
| D | % | 98 | 98 | 98 | 98 | 98 | 57 | 98 | 98 | 98 | 98 | 98 |
| C | % | 89 | 81 | 80 | 82 | 81 | 67 | 83 | 82 | 82 | 82 | 82 |
| B | % | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| A | % | 99 | 99 | 100 | 100 | 99 | 29 | 98 | 98 | 99 | 99 | 99 |
| Aux. Air | % | 31 | 30 | 24 | 24 | 17 | 15 | 27 | 21 | 17 | 15 | 19 |
| Opacity Meter/Observor | % | --/25 | --/-- | --/-- | --/-- | --/20 | --/-- | --/-- | --/-- | --/15 | --/-- | --/-- |

# BOARD & COMPUTER DATA

| **TEST NO.** | | **15** | **16** | **17** | **18** | **19** | **20** | **21** | **22** | **23** | **24** | **25** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Load | MW | 409 | 401 | 368 | 370 | 402 | 402 | 402 | 404 | 403 | 402 | 403 |
| Date | 1979 | 1/23 | 1/24 | 1/24 | 1/24 | 1/25 | 1/25 | 1/25 | 1/25 | 1/25 | 1/25 | 1/25 |
| Time | HRS | 1600 | 1015 | 1345 | 1530 | 0900 | 0930 | 1000 | 1030 | 1300 | 1330 | 1400 |
| **TEMPERATURES - STEAM & WATER** | | | | | | | | | | | | |
| Feedwater to Economizer | °F | 498 | 498 | 488 | 488 | 498 | 497 | 497 | 498 | 498[T] | 498[T] | 498[T] |
| SH Outlet A | °F | 1005 | 1020 | 1014 | 1007 | 1008 | 1007 | 1000 | 1009 | 1000[T] | 990[T] | 995[T] |
| B | °F | 983 | 989 | 999 | 993 | 989 | 988 | 986 | 1000 | 1000[T] | 990[T] | 995[T] |
| Reheater Outlet A | °F | 998 | 1011 | 980 | 1007 | 1022 | 1012 | 1007 | 1016 | 1005[T] | 1000[T] | 1004[T] |
| B | °F | 1001 | 999 | 989 | 998 | 996 | 998 | 993 | 1006 | 1005[T] | 1000[T] | 1004[T] |
| **TEMPERATURES - AIR & GAS** | | | | | | | | | | | | |
| ient Air | °F | 39 | 38 | 37 | 33 | 24 | 24 | 25 | 24 | 25 | 25 | -- |
| ient Air Dew Point | °F | 38 | 32 | 31 | 30 | 20 | 21 | 21 | 21 | 21 | 21 | -- |
| Primary Air AH Inlet | °F | 97 | 98 | 98 | 98 | 97 | 96 | 98 | 98 | -- | -- | -- |
| AH Outlet | °F | 636 | 636 | 607 | 599 | 629 | 628 | 627 | 629 | -- | -- | -- |
| Mill Outlet, Pulverizer 5-E | °F | 174 | 174 | OFF | OFF | 182 | 184 | 184 | 182 | 160 | 155 | 156 |
| 5-D | °F | 133 | 131 | 133 | 136 | 146 | 146 | 146 | 148 | 155 | 155 | 157 |
| 5-C | °F | 173 | 172 | 175 | 176 | 179 | 180 | 180 | 180 | 165 | 165 | 162 |
| 5-B | °F | 142 | 143 | 145 | 145 | 143 | 143 | 143 | 144 | 150 | 150 | 152 |
| 5-A | °F | 128 | 134 | 134 | 135 | 134 | 134 | 134 | 134 | 150 | 150 | 151 |
| Secondary Air AH Inlet | °F | 100 | 100 | 123 | 126 | 104 | 104 | 105 | 105 | 92 | 95 | 95 |
| AH Outlet | °F | 558 | 559 | 542 | 544 | 562 | 560 | 560 | 562 | -- | -- | -- |
| Flue Gas Leaving Economizer | °F | 774 | 766 | 730 | 709 | 742 | 740 | 732 | 711 | -- | -- | -- |
| Flue Gas Entering AH | °F | 693 | 693 | 660 | 650 | 686 | 686 | 685 | 686 | -- | -- | -- |
| Flue Gas Leaving AH | °F | 314 | 315 | 312 | 312 | 320 | 312 | 312 | 313 | 305 | 305 | 305 |
| **MISCELLANEOUS** | | | | | | | | | | | | |
| Coal Feeder Rates Total | % | 80 | 79 | 71 | 71 | 83 | 83 | 83 | 83 | 84 | 84 | 83 |
| Coal Feeder Rates Feeder 5-E | $10^3$LB/HR | 64 | 56 | 0 | 0 | 70 | 70 | 70 | 73 | 70 | 66 | 65 |
| 5-D | $10^3$LB/HR | 80 | 79 | 84 | 85 | 77 | 77 | 76 | 77 | 79 | 78 | 76 |
| 5-C | $10^3$LB/HR | 65 | 65 | 72 | 71 | 75 | 75 | 75 | 75 | 76 | 76 | 75 |
| 5-B | $10^3$LB/HR | 82 | 79 | 85 | 87 | 75 | 76 | 75 | 77 | 77 | 80 | 75 |
| 5-A | $10^3$LB/HR | 71 | 75 | 82 | 84 | 75 | 76 | 75 | 76 | 76 | 78 | 75 |
| Windbox Damper Pos. OFA GG | % | 0 | 50 | 50 | 50 | 50 | 50 | 75 | 75 | 100 | 0 | 100 |
| OFA FF | % | 0 | 50 | 50 | 50 | 50 | 0 | 0 | 75 | 100 | 100 | 0 |
| Fuel Air E | % | 77 | 57 | 0 | 0 | 93 | 93 | 89 | 90 | 89 | 84 | 86 |
| D | % | 98 | 98 | 98 | 98 | 98 | 98 | 98 | 98 | 98 | 98 | 98 |
| C | % | 82 | 82 | 97 | 97 | 99 | 98 | 98 | 98 | 98 | 98 | 99 |
| B | % | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| A | % | 99 | 98 | 98 | 99 | 99 | 99 | 99 | 99 | 99 | 100 | 99 |
| Aux. Air | % | 30 | 22 | 19 | 13 | 15 | 17 | 18 | 14 | 17 | 17 | 18 |
| Opacity Meter/Observer | % | --/-- | --/-- | --/-- | --/-- | --/15 | --/-- | --/10 | --/10 | --/-- | --/-- | --/-- |

[T] Average of A & B temperatures.

# BOARD & COMPUTER DATA

| TEST NO. | | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Load | MW | 404 | 323 | 321 | 325 | 327 | 303 | 307 | 341 | 342 | 343 | 255 |
| Date | 1979 | 1/25 | 1/30 | 1/30 | 1/30 | 1/30 | 1/31 | 1/31 | 2/1 | 2/1 | 2/1 | 2/6 |
| Time | HRS | 1430 | 1045 | 1145 | 1245 | 1330 | 1400 | 1500 | 1000 | 1100 | 1345 | 0005 |
| **TEMPERATURES - STEAM & WATER** | | | | | | | | | | | | |
| Feedwater to Economizer | °F | -- | 473 | 473 | 474 | 474 | 468 | 468 | 479 | 479 | 480 | 450 |
| SH Outlet A | °F | 1022 | 1000 | 1012 | 1006 | 1009 | 1005 | 1012 | 1012 | 991 | 1001 | 1011 |
| B | °F | 1001 | 956 | 980 | 985 | 980 | 980 | 991 | 980 | 985 | 973 | 1017 |
| Reheater Outlet A | °F | 1030 | 969 | 984 | 988 | 981 | 975 | 986 | 1006 | 981 | 1004 | 975 |
| B | °F | 1000 | 983 | 964 | 971 | 956 | 958 | 975 | 977 | 992 | 986 | 976 |
| **TEMPERATURES - AIR & GAS** | | | | | | | | | | | | |
| ent Air | °F | 23 | 22 | 25 | 25 | 26 | 25 | 25 | 16 | 19 | 21 | 2 |
| ent Air Dew Point | °F | 22 | 18 | 22 | 23 | 24 | 24 | 24 | 13 | 17 | 21 | -1 |
| Primary Air AH Inlet | °F | 97 | 95 | 95 | 95 | 95 | 100 | 100 | 102 | 102 | 102 | 105 |
| AH Outlet | °F | 629 | 592 | 568 | 593 | 573 | 566 | 560 | 584 | 584 | 582 | 550 |
| Mill Outlet, Pulverizer 5-E | °F | 180 | 166 | 160 | 161 | 159 | 157 | 168 | 157 | 160 | 161 | OFF |
| 5-D | °F | 149 | 147 | 149 | 149 | 148 | 146 | 149 | 154 | 158 | 159 | 150 |
| 5-C | °F | 180 | OFF | OFF | OFF | OFF | OFF | OFF | OFF | OFF | OFF | OFF |
| 5-B | °F | 143 | 145 | 144 | 144 | 144 | 145 | 145 | 140 | 140 | 138 | 155 |
| 5-A | °F | 132 | 142 | 142 | 142 | 142 | 148 | 149 | 156 | 155 | 156 | 154 |
| Secondary Air AH Inlet | °F | 104 | 144 | 163 | 146 | 160 | 130 | 132 | 145 | 144 | 144 | 152 |
| AH Outlet | °F | 563 | 533 | 533 | 535 | 534 | 519 | 517 | 535 | 537 | 534 | 508 |
| Flue Gas Leaving Economizer | °F | 707 | 678 | 668 | 682 | 665 | 664 | 652 | 667 | 653 | 695 | 667 |
| Flue Gas Entering AH | °F | 687 | 643 | 609 | 645 | 617 | 616 | 608 | 632 | 633 | 630 | 595 |
| Flue Gas Leaving AH | °F | 313 | 315 | 320 | 318 | 320 | 299 | 299 | 315 | 315 | 315 | 305 |
| **MISCELLANEOUS** | | | | | | | | | | | | |
| Coal Feeder Rates Total | % | 81 | 72 | 71 | 73 | 72 | 63 | 63 | 67 | 67 | 69 | 50 |
| Coal Feeder Rates Feeder 5-E | $10^3$LB/HR | 56 | 81 | 81 | 81 | 81 | 78 | 74 | 73 | 72 | 73 | 0 |
| 5-D | $10^3$LB/HR | 84 | 83 | 81 | 83 | 81 | 71 | 69 | 79 | 78 | 79 | 77 |
| 5-C | $10^3$LB/HR | 75 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5-B | $10^3$LB/HR | 82 | 82 | 80 | 81 | 81 | 67 | 60 | 78 | 77 | 78 | 76 |
| 5-A | $10^3$LB/HR | 82 | 84 | 80 | 81 | 80 | 71 | 71 | 77 | 76 | 77 | 76 |
| Windbox Damper Pos. OFA GG | % | 75 | 5 | 5 | 50 | 50 | 100 | 100 | 100 | 75 | 75 | 5 |
| OFA FF | % | 75 | 5 | 5 | 50 | 50 | 100 | 100 | 100 | 75 | 75 | 5 |
| Fuel Air E | % | 71 | 98 | 98 | 98 | 98 | 98 | 98 | 98 | 97 | 98 | 0 |
| D | % | 98 | 98 | 99 | 99 | 99 | 99 | 98 | 98 | 98 | 98 | 98 |
| C | % | 98 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| B | % | 100 | 100 | 100 | 100 | 100 | 89 | 89 | 100 | 100 | 100 | 100 |
| A | % | 99 | 99 | 99 | 99 | 99 | 99 | 99 | 100 | 99 | 99 | 98 |
| Aux. Air | % | 17 | 23 | 14 | 17 | 15 | 13 | 13 | 15 | 13 | 13 | 16 |
| Opacity Meter/Observer | % | --/-- | --/<20 | --/<20 | --/-- | --/-- | --/-- | --/-- | --/-- | --/-- | --/-- | --/-- |

# BOARD & COMPUTER DATA

| **TEST NO.** |  | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Load | MW | 255 | 254 | 253 | 253 | 306 | 307 | 309 | 353 | 353 | 355 | 147 |
| Date | 1979 | 2/6 | 2/6 | 2/6 | 2/6 | 2/7 | 2/7 | 2/7 | 2/12 | 2/12 | 2/12 | 2/14 |
| Time | HRS | 0100 | 0120 | 0220 | 0320 | 0020 | 0040 | 0255 | 1130 | 1210 | 1300 | 0015 |
| **TEMPERATURES - STEAM & WATER** |  |  |  |  |  |  |  |  |  |  |  |  |
| Feedwater to Economizer | °F | 449 | 448 | 449 | 449 | 467 | -- | 466 | 481 | 482 | -- | 400 |
| SH Outlet A | °F | 1004 | 1012 | 996 | 1008 | 1025 | 1045 | 1034 | 986 | 988 | 989 | 1010 |
| B | °F | 977 | 956 | 969 | 986 | 986 | 1014 | 1001 | 997 | 1006 | 999 | 1006 |
| Reheater Outlet A | °F | 963 | 955 | 948 | 960 | 1006 | 1022 | 990 | 1002 | 1001 | 1010 | 978 |
| B | °F | 940 | 924 | 925 | 951 | 992 | 1013 | 1010 | 997 | 1008 | 1004 | 955 |
| **TEMPERATURES - AIR & GAS** |  |  |  |  |  |  |  |  |  |  |  |  |
| bient Air | °F | 0 | 0 | -1 | -2 | 20 | 20 | 22 | 21 | 22 | 22 | 6 |
| mbient Air Dew Point | °F | -3 | -4 | -4 | -5 | 20 | 20 | 21 | 15 | 16 | 16 | 2 |
| Primary Air AH Inlet | °F | 105 | 106 | 106 | 106 | 102 | 102 | 102 | 100 | 102 | 105 | 105 |
| AH Outlet | °F | 545 | 544 | 540 | 542 | 576 | 574 | 571 | 591 | 591 | 593 | 508 |
| Mill Outlet, Pulverizer 5-E | °F | OFF | OFF | OFF | OFF | 154 | 156 | 153 | 167 | 169 | 167 | 153 |
| 5-D | °F | 148 | 147 | 149 | 149 | 150 | 147 | 147 | 158 | 158 | 158 | 153 |
| 5-C | °F | OFF | OFF | OFF | OFF | OFF | OFF | OFF | OFF | OFF | OFF | OFF |
| 5-B | °F | 155 | 155 | 155 | 155 | 150 | 150 | 138 | 153 | 144 | 144 | OFF |
| 5-A | °F | 152 | 151 | 151 | 152 | 153 | 154 | 154 | 152 | 152 | 153 | OFF |
| Secondary Air AH Inlet | °F | 157 | 158 | 159 | 159 | 148 | 150 | 151 | 108 | 110 | 111 | 151 |
| AH Outlet | °F | 508 | 508 | 506 | 507 | 532 | 537 | 530 | 536 | 536 | 539 | 478 |
| Flue Gas Leaving Economizer | °F | 458 | 657 | 645 | 646 | 700 | 701 | 679 | 710 | 704 | 714 | 572 |
| Flue Gas Entering AH | °F | 588 | 587 | 583 | 584 | 627 | 620 | 617 | 642 | 641 | 644 | 550 |
| Flue Gas Leaving AH | °F | 306 | 305 | 305 | 304 | 315 | 315 | 314 | 300 | 302 | 303 | 285 |
| **MISCELLANEOUS** |  |  |  |  |  |  |  |  |  |  |  |  |
| Coal Feeder Rates Total | % | 49 | 50 | 48 | 50 | -- | -- | -- | -- | -- | -- | -- |
| Coal Feeder Rates Feeder 5-E | $10^3$LB/HR | 0 | 0 | 0 | 0 | 45 | 45 | 40 | 73 | 76 | 72 | 53 |
| 5-D | $10^3$LB/HR | 77 | 75 | 74 | 72 | 69 | 68 | 73 | 75 | 77 | 74 | 56 |
| 5-C | $10^3$LB/HR | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5-B | $10^3$LB/HR | 78 | 76 | 75 | 74 | 77 | 73 | 81 | 75 | 76 | 73 | 0 |
| 5-A | $10^3$LB/HR | 77 | 74 | 73 | 74 | 77 | 85 | 81 | 72 | 75 | 75 | 24 |
| Windbox Damper Pos. OFA GG | % | 50 | 75 | 100 | 5 | 5 | 50 | 100 | 100 | 100 | 100 | 0 |
| OFA FF | % | 50 | 75 | 100 | 5 | 5 | 50 | 100 | 100 | 100 | 100 | 0 |
| Fuel Air E | % | 0 | 0 | 0 | 0 | 30 | 32 | 20 | 98 | 98 | 98 | 52 |
| D | % | 98 | 98 | 98 | 98 | 90 | 88 | 98 | 98 | 98 | 98 | 62 |
| C | % | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| B | % | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 0 |
| A | % | 98 | 98 | 98 | 98 | 98 | 98 | 98 | 99 | 99 | 99 | 0 |
| Aux. Air | % | 13 | 13 | 13 | 14 | 15 | 15 | 14 | 14 | 14 | 14 | 14 |
| Opacity Meter/Observer | % | --/-- | --/-- | --/-- | --/-- | --/-- | --/-- | --/-- | --/-- | --/-- | --/-- | --/-- |

## KDL FUEL'S LABORATORY
## COAL AND/OR ASH ANALYSES REPORT

Company Columbus & Southern Ohio Electric Co.

Project 826115

Station Conesville Unit #5

Date March 30, 1979

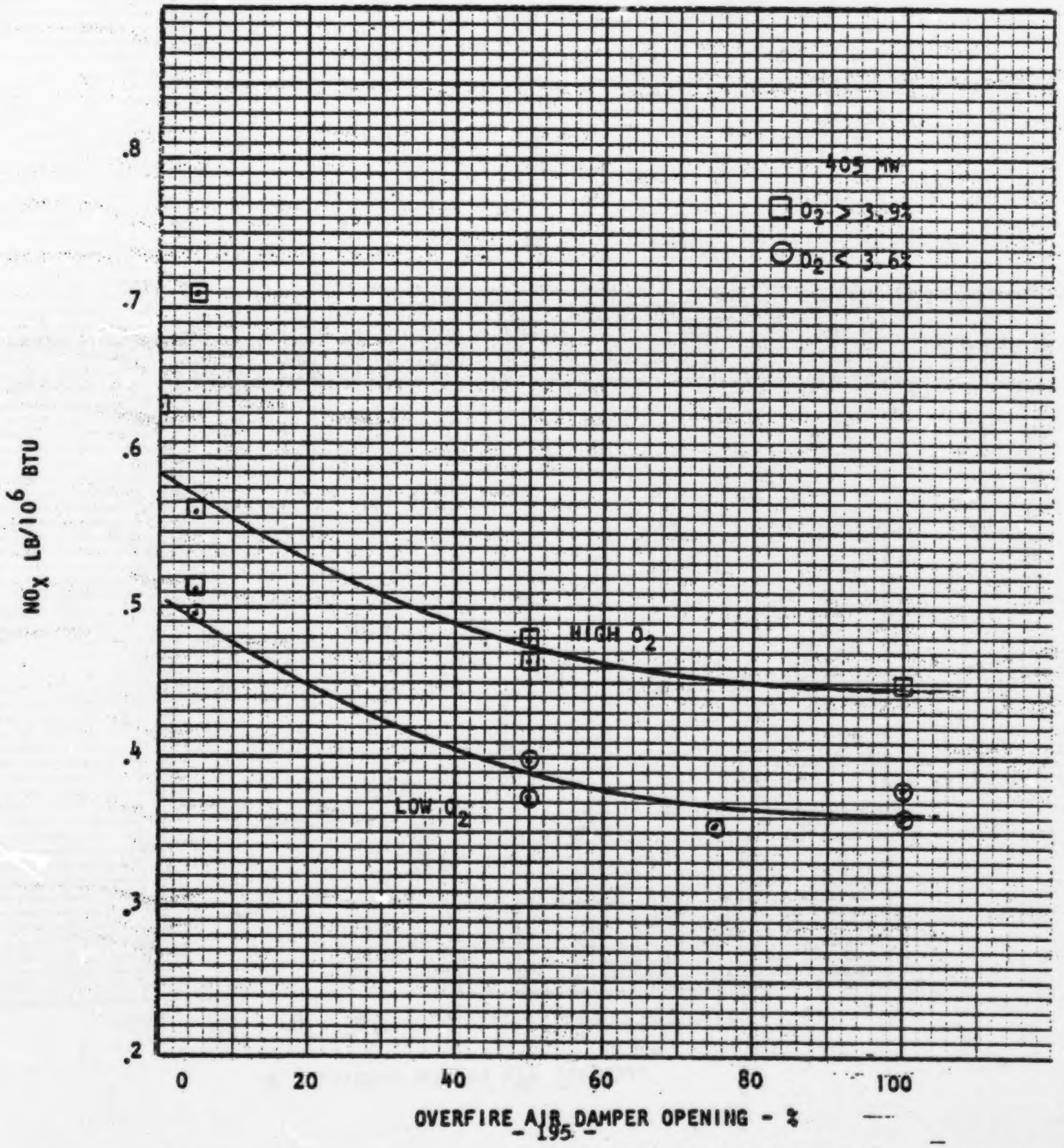
Contract 8872

Standard List No.

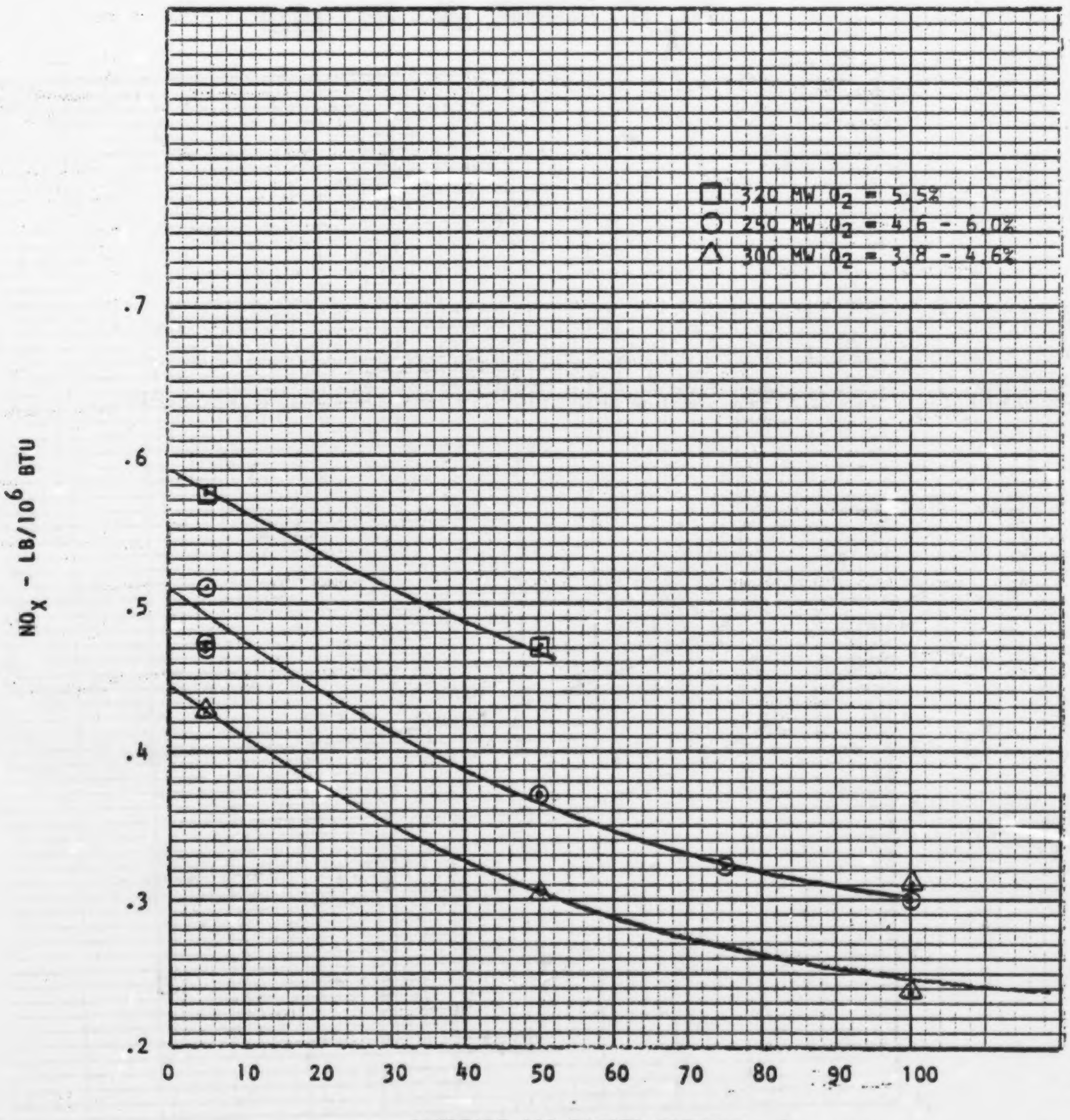
| Sample Ident. | 1/25/79 | 1/31/79 | 2/8/79 | |
|---|---|---|---|---|
| KDL Number | 6418-C | 6419-C | 6420-C | |
| Report Basis | As received | As received | As received | |
| Proximate Weight % | | | | |
| Moisture | 8.3 | 10.5 | 9.2 | |
| Volatile Matter | 34.5 | 36.1 | 34.4 | |
| Fixed Carbon | 40.9 | 41.5 | 40.5 | |
| Ash | 16.3 | 11.9 | 15.9 | |
| Total | 100.0% | 100.0% | 100.0% | |
| HHV, Btu/lb | 10,625 | 10,790 | 10,380 | |
| B Ash/mm Btu | | | | |
| Ultimate | | | | |
| Moisture | 8.3 | 10.5 | 9.2 | |
| Hydrogen | 4.2 | 4.5 | 4.2 | |
| Carbon | 58.2 | 60.1 | 57.8 | |
| Sulfur | 3.8 | 3.3 | 4.1 | |
| Nitrogen | 1.0 | 0.7 | 0.6 | |
| Oxygen (dif.) | 8.2 | 9.0 | 8.2 | |
| Ash | 16.3 | 11.9 | 15.9 | |
| Total | 100.0% | 100.0% | 100.0% | |
| Grindability | | | | |
| Ash Fusibility | | | | |
| I.T.°F | | | | |
| S.T.°F | | | | |
| H.T.°F | | | | |
| F.T.°F | | | | |
| Ash Composition | | | | |
| A $SiO_2$ | | | | |
| A $Al_2O_3$ | | | | |
| B $Fe_2O_3$ | | | | |
| B CaO | | | | |
| B MgO | | | | |
| B $Na_2O$ | | | | |
| B $K_2O$ | | | | |
| A $TiO_2$ | | | | |
| $SO_3$ | | | | |
| $P_2O_5$ | | | | |
| Total | | | | |
| B/A Ratio | | | | |
| $Fe_2O_3$/CaO Ratio | | | | |

Signature March 30, 1979

## $NO_X$ VS. OVERFIRE AIR - FULL LOAD



## $NO_X$ VS. OVERFIRE AIR - REDUCED LOAD



creasing the damper opening from 50% to 100%. Little change in $NO_x$ emission was observed between 75 and 100% overfire air damper opening.

Reducing excess air was also an effective means of reducing $NO_x$. At full load, $NO_x$ emission could be reduced approximately 19% by decreasing excess air from 25% to 15% regardless of the OFA damper opening. The following sheets are plots of $NO_x$ versus excess air with constant overfire air damper openings for full load and 78% load, respectively.

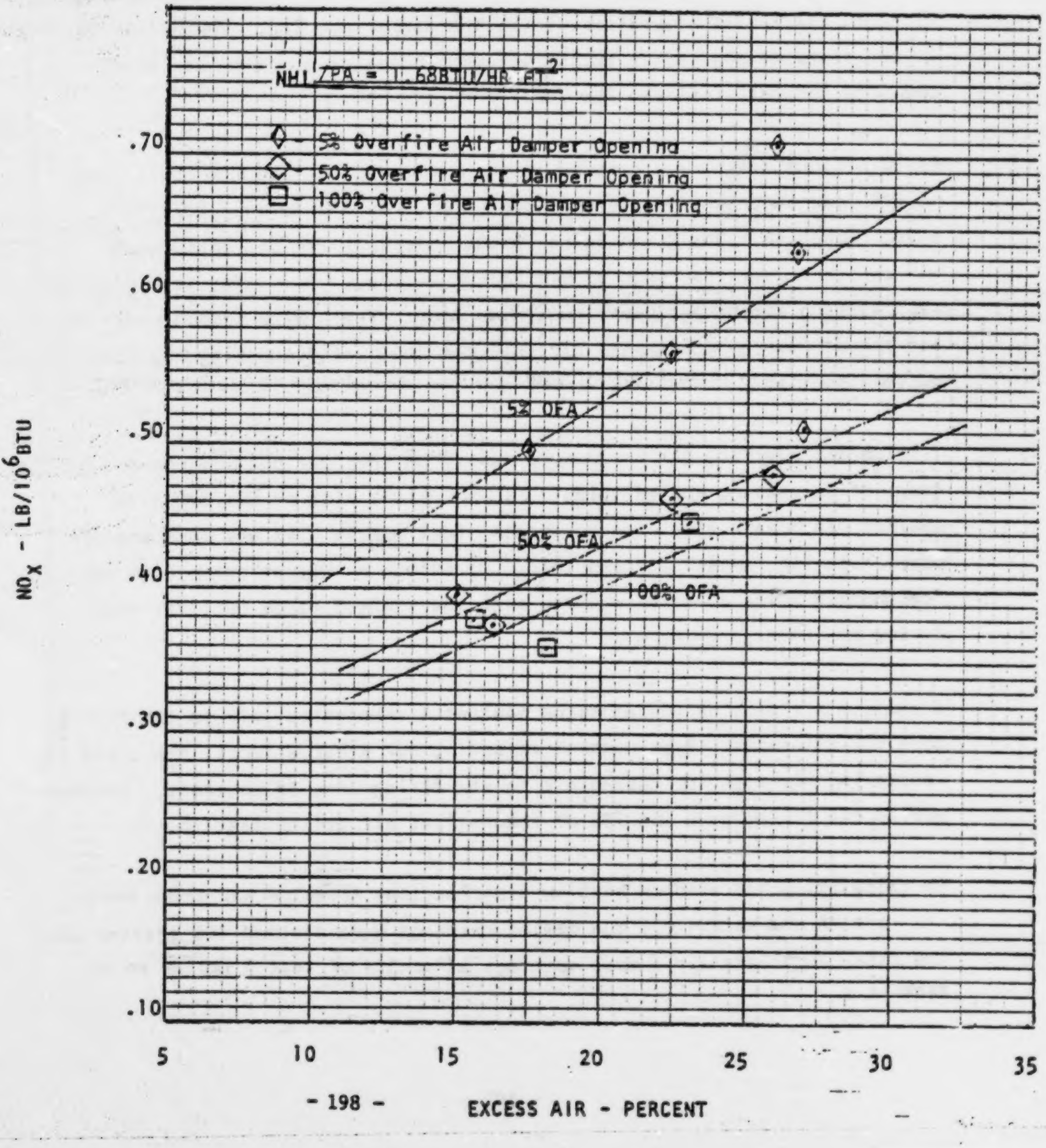
Using minimum overfire air damper openings, reducing load from full load to 62% load decreased $NO_x$ levels from .618 LB/$10^6$BTU to .483 LB/$10^6$BTU, a 22% reduction. The % reduction in $NO_x$ emission with decreased load was constant over the range of OFA damper settings. Following is a plot of $NO_x$ emission versus Net Heat Input/Plan Area. Tests with common overfire air damper opening and excess air show the trend of decreasing $NO_x$ with decreasing load.

Tilting the overfire air nozzles up away from the fuel nozzles shows a slight trend of decreasing $NO_x$ emission. Following is a plot of $NO_x$ emission against OFA nozzle tilt with horizontal fuel nozzle tilt and constant OFA damper opening, excess air and load. No effect on $NO_x$ emission from varying fuel nozzle tilts could be noticed over the limited range of tilts used during the test program.

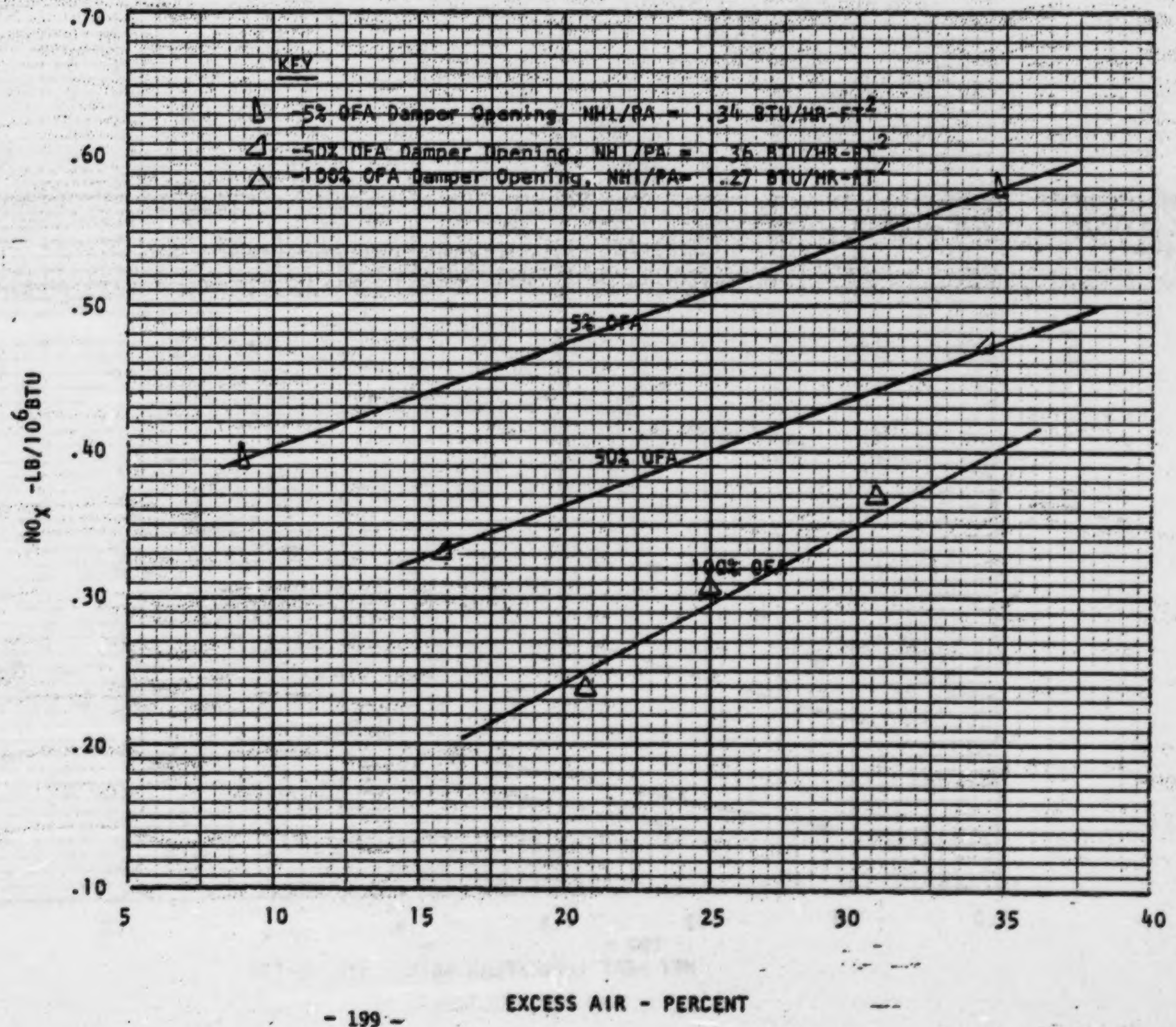
Finally, is a plot of $NO_x$ emission against % theoretical air to the firing zone for all tests. Even without adjusting for other effects, the trend of increasing $NO_x$ with increasing air to the firing zone is apparent. Minimum air to the firing zone was 79% of theoretical air during test 18.

In calculating the windbox airflow distributions, (results not shown here), the AA and warmup oil gun damper openings were assumed 10% greater than the other auxiliary air damper openings. (Results of test 3 follow as an example.)

## $NO_X$ VS. EXCESS AIR
## FULL LOAD



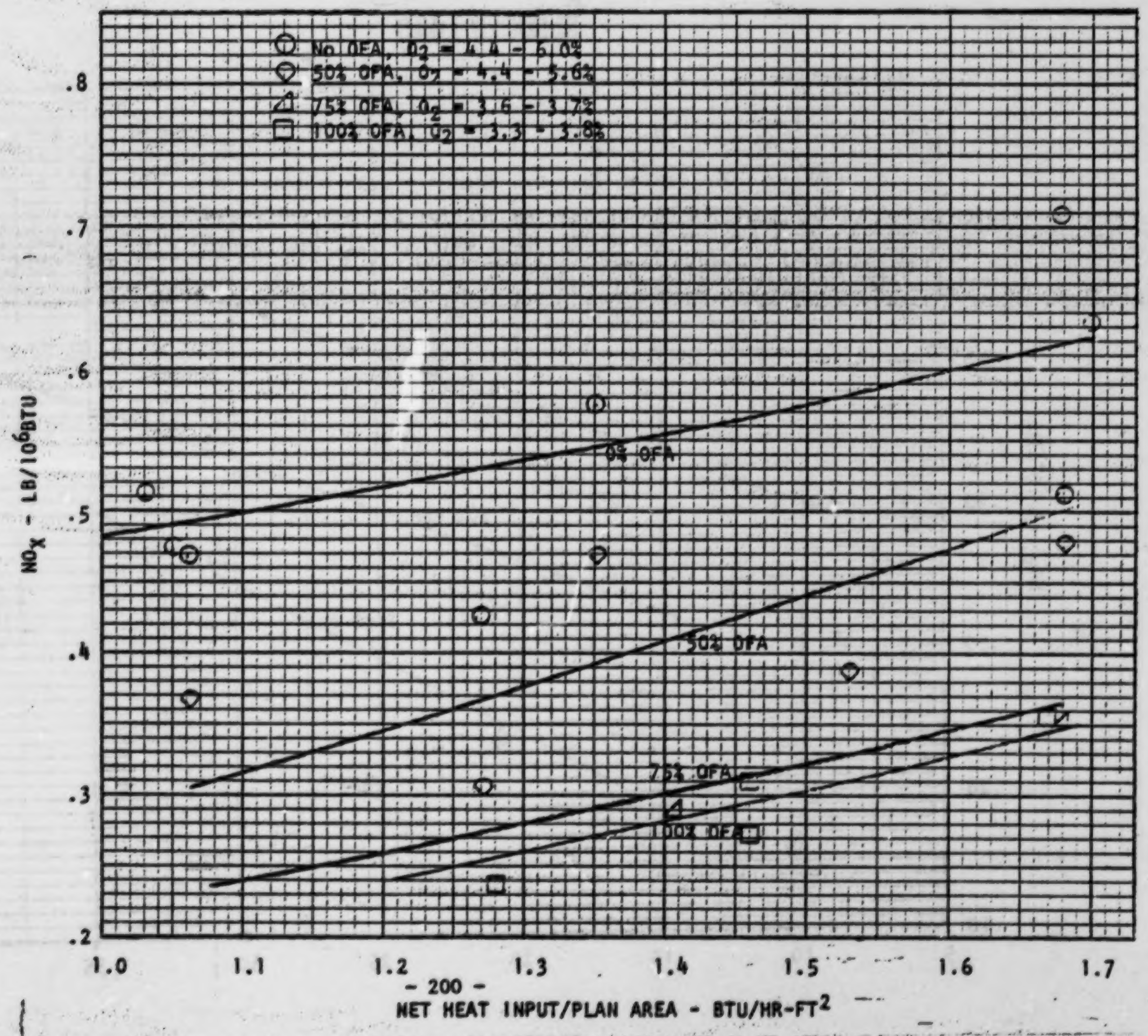
## $NO_X$ VS. EXCESS AIR
## REDUCED LOAD



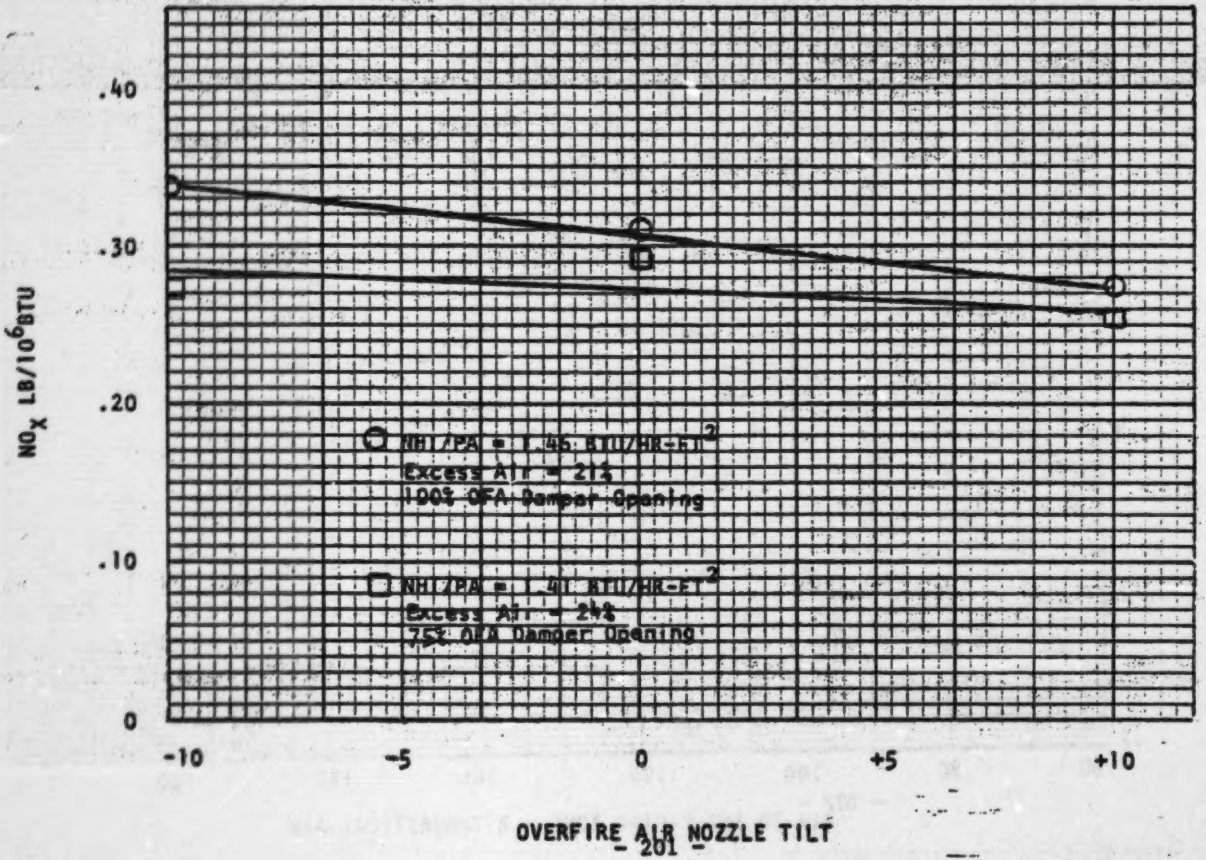
Columbus and Southern Ohio Electric Co.
Conesville #5
Contract 8872
Project 826115

C-E Power Systems
Field Testing &
Performance Results

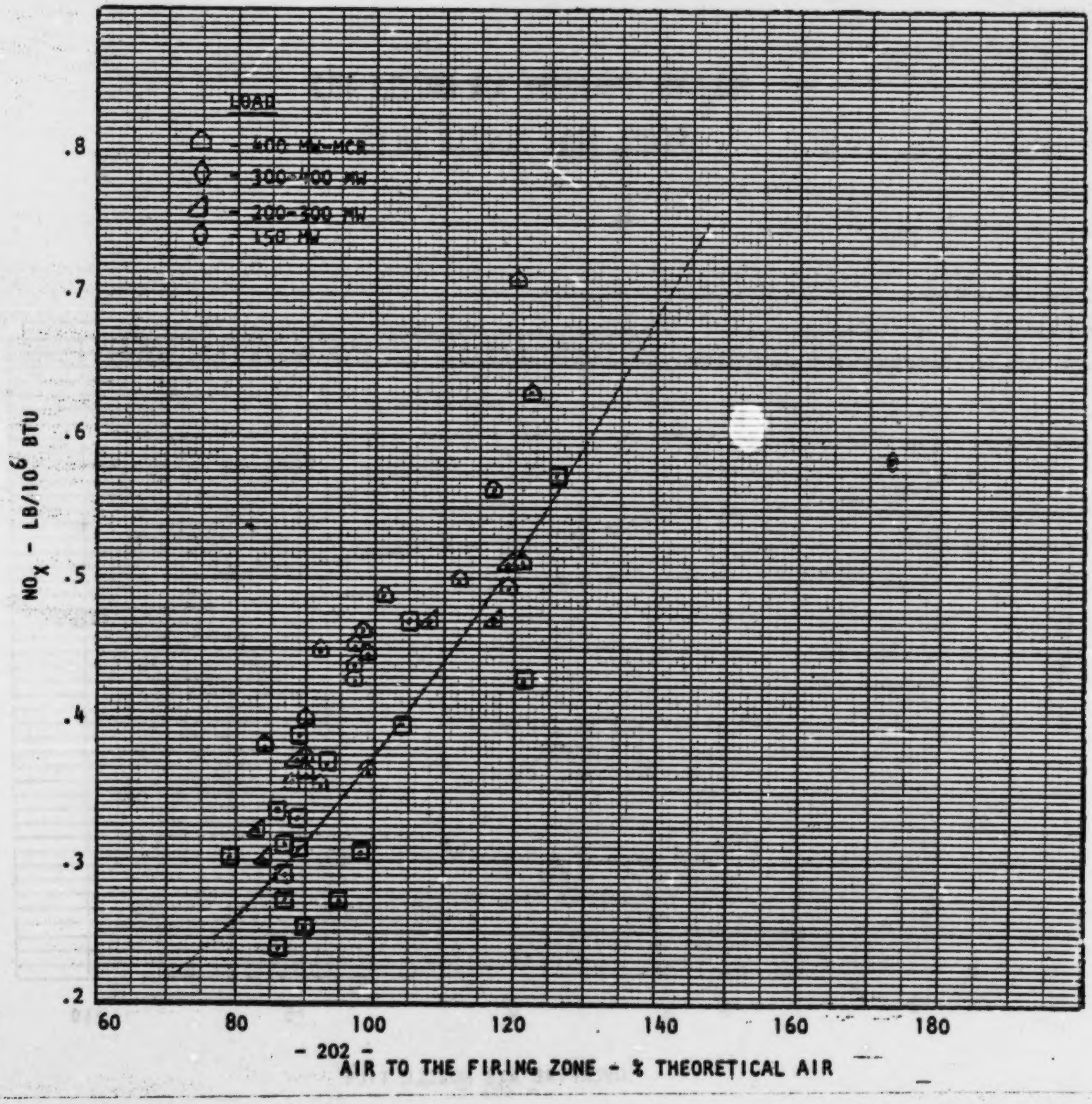
## $NO_X$ VS. NHI/PA



## $NO_X$ VS. OVERFIRE AIR NOZZLE TILT
## HORIZ. FUEL NOZZLE TILTS



## $NO_X$ VS. AIR TO THE FIRING ZONE
## ALL TESTS



# WINDBOX COMPARTMENT AIR DISTRIBUTION

FLOW DISTRIBUTION FOR TEST NO. 3

PERCENT EXCESS AIR 25.9

| COMPARTMENT (NO.) | FIRING | AREA WT. FLOW (% OF TOTAL) | DAMPERS (% OPEN) | ACTUAL FLOW (% OF TOTAL) |
|---|---|---|---|---|
| 1 | | 7.01 | 5. | 0.73 |
| 2 | | 7.01 | 5. | 0.73 |
| 3 | | 7.58 | 31. | 5.76 |
| 4 | YES | 2.24 | 73. | 5.88 |
| 5 | | 16.21 | 31. | 12.52 |
| 6 | YES | 2.24 | 98. | 8.00 |
| 7 | | 16.21 | 31. | 12.52 |
| 8 | YES | 2.24 | 89. | 8.04 |
| 9 | | 16.21 | 31. | 12.52 |
| 10 | YES | 2.24 | 100. | 8.14 |
| 11 | | 2.53 | 31. | 1.30 |
| 12 | | 5.91 | 41. | 6.85 |
| 13 | | 2.53 | 31. | 1.30 |
| 14 | YES | 2.24 | 99. | 8.05 |
| 15 | | 7.58 | 41. | 7.66 |

FIRING FUEL COMPARTMENT TOTAL AIR FLOW(%) = 38.18
AIR FLOW ABOVE BURNER ZONE (%) = 4.35
AIR FLOW TO BURNER ZONE (%OF THEOR. AIR) = 121.42

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Damper positions were taken from the board data. Primary air flow was assumed to be 5% of the total air flow for each mill in service. Thus, primary air was assumed to be 25% for the tests with 5 mills, 20% for tests with 4 mills and 15% for tests with 3 mills in service. An explanation of output from the program used to calculate the windbox airflow distributions is on the next page.

After January 25, 1979, the "C" elevation coal pulverizer was taken out of service for maintainance. "C" mill was not available for service during the duration of the test program. Maximum load was limited during Tests 27 through 47 by having only 4 mills available.

## TEST METHODS

Exxon Research uses the following analyzers to monitor emission levels; Beckman non-dispersive infrared for NO, CO, $CO_2$, and $SO_2$; Beckman non-dispersive ultra-violet for $NO_x$; two polarographic analyzers for $O_2$; and a chemiluminesence analyzer for $NO_x$. These instruments are housed in Exxon's sampling-analytical van. Gas samples are drawn from a 12 point (4 probes-three points per probe) sampling grid in the economizer outlet duct. Particulate is removed from the sample gas by a heated filter. Moisture is removed from the sample gas by a permeable membrane dryer. The samples from each probe are pumped to the sample van by 4 individual pumps and sample lines to allow comparisons of gas analysis from individual probes.

George H. Scharpf, Jr.

George H. Scharpf, Jr.

GHS:jms

Attachments

## EXPLANATION OF WINDBOX AIRFLOW DISTRIBUTIONS

1. The "AREA WT. FLOW" is the ratio of the compartment free area to the total free area of the corner; as such it is a realistic approximation of the actual compartment (Secondary) flow only when all compartment dampers are full open.

2. The compartment "ACTUAL FLOW" is the ratio of the compartment mass flow rate (including mill air if applicable) to the total mass flow to the corner.

3. The "FIRING FUEL COMPARTMENT TOTAL AIR FLOW" is the ratio of the total mass flow rate to firing fuel compartments (including mill air if applicable) to the total mass flow to the corner.

4. The "AIR FLOW ABOVE BURNER ZONE" is defined as the percentage of the total mass flow rate supplied above the uppermost firing fuel compartment, less 50% of the flow to the compartment immediately above it.

5. % Theoretical Air to the Burner Zone = $\left(1 - \frac{\text{\% Air Above Burner Zone}}{100}\right)$ (100 + % Excess Air).

## APPENDIX H

## EXXON SASS AND LEVEL 1 DATA
## (SUMMARY OF EXXON RESULTS AT PRECIPITATOR INLET)

| | Page |
|---|---|
| o Validity of cyclone cut points | 207 |
| o Sample volumes | 208 |
| o Laboratory report (selected sections) | 210 |

## Validity of Cyclone Cutpoints

At meter conditions (Dry - 0% $H_2O$, 6.65% $O_2$, $T_{avg}$ = 78.5°F, $P_{avg}$ = 29.6" Hg), 764.4 $ft^3$ (DACF) was sampled (see Table HH-2). This means that the actual quantity of (wet) gas that passed through the cyclones (at 6.85% $H_2O$, Tavg = 409°F, Pavg = 28.5" Hg) then was:

$$Q_{cyclones} = \left(\frac{764.4}{1 - 0.0685}\right)\left(\frac{460 + 409}{460 + 78.5}\right)\left(\frac{29.6}{28.5}\right)$$

$$= 1{,}375 \text{ ft}^3 \text{ (WACF)}$$

Since actual sampling time was 261 min, the average flow rate through the cyclones was 5.27 ACF/min. The cyclone cut points are calibrated for 6.5 ACF/min. Therefore, because sampling occurred somewhat slower than the design rate, the cutpoints of the cyclones may be somewhat different from the 1, 3, and 10 μm for which they were designed. The change should not be significant in the smallest cyclone, but for the two largest cyclones, a square root relationship with flow is expected. This leads to the conclusion that instead of 1, 3, and 10 μm, the cutpoints were 1, 4 1/2, and 15 μm, respectively.

Sampling was done isokinetically (%I = 101.9) thus insuring that the sample is representative. Furtherfore, subsequent morphological analysis by microscopy (discussed later in this appendix, and also in Section IV of part C of this report) revealed that the cyclones had done a remarkably good job of separating the particles according to size.

## TABLE GH-1

## SASS SAMPLE SIZES
(Field Measurements*)

| | | |
|---|---|---|
| Volume of Gas Sampled (also, see next page) | | 750 ft$^3$ |
| 1st Impinger ($H_2O_2$) | | |
| Pre-test | 500 mL | |
| Post-test | | Not measured |
| 1st rinse | | 750 mL |
| Other sources (by difference) | | 880 mL** |
| Shipped to Linden for Analysis | | 2130 mL |
| 2nd Impinger ($AgNO_3$, etc.) | | |
| Pre-test | 500 mL | |
| Post-test | | 646 mL |
| 1st rinse (by difference) | | 500 mL |
| Shipped to Linden for Analysis | | 1146 mL*** |
| 3rd Impinger ($AgNO_3$, etc.) | | |
| Pre-test | 500 mL | |
| Post-test | | 226 mL**** |
| 1st rinse | | 250 mL |
| Shipped to Linden for Analysis | | 476 mL*** |
| Organic Module | | |
| Condensate | | 495 mL***** |
| $CH_2Cl_2$ Rinse | | 1765 mL |
| 4th Impinger (silica gel) 1st Batch | | |
| Pre-test gross weight (includes tare wt: | 1823 g) | 2573 g |
| Post-test gross weight (includes tare wt: | 1823 g) | 2887 g |
| Weight gain ($H_2O$) | | 314 g****** |

*Other sample size descriptions are included in the laboratory report on the following pages in this appendix.

**Calculated by difference. Includes (probable amounts):

| | |
|---|---|
| Condensed water | 75 mL |
| Overflow from organic condensate trap | 600 mL |
| Part of impinger No. 3 erroneously mixed in | 150-250 mL |
| Backflush from impinger No. 2 | 0 mL |

***After the catches and washings from impinger 2 and 3 were shipped to the laboratory, they were mixed. The resulting weight was 1530.2 g. Assuming a specific gravity of 1, this means that 92 mL (or 6% of the sample, leaked out in shipping. ( 1146 + 476 = 1622 mL were shipped, but only 1530 mL were received.)

****This was measured after some (probably 200-300 mL) was erroneously spilled into and mixed with the impinger No. 1 catch.

*****This is the maximum capacity of the catch pan and does not include the portion of the catch that overflowed into the 1st impinger.

******The silica gel was probably used beyond the point of saturation. Initial weight of the dry silica gel: (gross)-(tare) = 750 g.

## TABLE GH-2

## SASS OPERATING LOG SUMMARY AND EARLY CALCULATED RESULTS

| | | |
|---|---|---|
| Start Time | 9-10-80 | 16:18 |
| End Time | 9-10-80 | 22:02 |
| Elapsed Time | | 5:44 |
| Sampling Time (probe actually in duct) | | 4:21 |
| Gas Volume Sampled (actual volume at meter) (DACF at 78.5°F, 29.6" Hg, 6.65% $O_2$* does not consider leaks) | | 764.4 ft$^3$ |
| Gas Volume Sampled (corrected to standard conditions) (DSCF (0% $H_2O$) @ 20°C (68°F), and 29.92" Hg (1 Atm), 6.65% $O_2$) | | 741.6 ft$^3$ |
| Avg. Stack Temp. | | 319°F |
| Nozzle Size | | 5/8 in. (dia) |
| Velocity Head (Pitot Tube Readings) | | |
| ($\Delta P$) avg. | | 0.3033 in $H_2O$ |
| ($\sqrt{\Delta P}$) avg. | | 0.551 |
| Stack velocity (single point test avg.) | | 38.34** ft/sec |
| Percent of isokinetic rate | | 101.9 |
| Initial Leak Rate | | |
| Entire train at >20" Hg vacuum | | <0.03 ft$^3$/min |
| Final Leak Rate | | |
| Entire train at 10" Hg vacuum | | <0.01 ft$^3$/min |
| Through organic module at 20" Hg vacuum | | <0.01 ft$^3$/min |
| Percent $H_2O$ in the duct | | 8.7%*** |

---

*From Entropy's Method 17 report (Appendix F).

**Average stack velocity by Method 17 = 42.0 ft/sec. (See Appendix F.) (The SASS method gives an average of many readings at a single point, while Method 17 gives an average of many single readings at many points).

***Entropy's Method 17 results (Appendix F) give water concentration as 5.95 vol % at the ESP inlet. The SASS method is probably not as reliable as the value resulting from Method 17, since assumptions having large "error bars" were made where SASS data was missing.

# LABORATORY REPORT (LEVEL 1 TEST)

## 1.0 Summary

Stack emission samples collected from a coal-fired utility boiler were analyzed for inorganic and organic constituents. A SASS train sampling device was used to collect emissions from the Conesville No. 5 Boiler. The nominal flue gas volume sampled was 30 $m^3$. As part of the EPA Level 1 test, microscopy and metal analyses were performed on the particulates. Quantities of extractable organics were measured and where sufficient amounts existed, more detailed functional group characterizations were performed.

Extractable organics were 55 mg for the Conesville test. The majority (> 90%) of these compounds were found on the XAD-2 organic adsorbent resin. It should be noted that about 50% of the Conesville extract may be due to XAD-2 blank contaminants. GC/MS and FTIR analyses of certain sample extracts identified low levels of aliphatic acids, and alkyl esters.

Scanning electron microscopy performed on the particulates generally showed good size fractionation in the SASS 10, 3, and 1 µm cyclones although some <3 µm particles were in the 10 and 3 µm cyclones.*

ICPES metal analysis showed that most metals had generally higher g/g concentrations on the smaller particulates. However, less than 5% of the total metal emissions were collected in the 1 micron cyclone. In general, the levels of most toxic metals were low (< 100 mg/SASS test) and near the ICPES detection limits.

## 2.0 Introduction

In September and October, 1980, the Exxon Tiger Van crew collected stack emission samples from a high-sulfur coal-combustion utility boiler. One objective of the EPA sponsored study (contract number EPA-68-02-2696) was to determine if toxic materials are being emitted.

## 3.0 Sampling and Analysis

Stack emission samples were collected using the SASS (Source Assessment Sampling System). A diagram detailing the various components of the system is illustrated in Figure C-II-4 of the main body of this report.

---

*See "Validity of Cyclone Cutpoints" at beginning of this appendix.

Flue gases first pass through a five-foot, heated, stainless steel probe and then into an oven. Both the probe and oven were maintained at 400°F to prevent condensation of the organics. Three cyclones, located in the oven, were used to separate particles by size (10, 3, and 1 µm*). A filter was used to collect material less than 1 micrometer in diameter. Hot gases were then cooled to about 70°F. The resulting condensate and remaining gases passed through a XAD-2 cartridge to adsorb organic compounds. The condensate then drains into a collection trap and the gases pass through a series of impinger solutions.

The first impinger (30% $H_2O_2$) traps reducing gases such as $SO_2$ to prevent a reduction in oxidative capability of the next two impingers. The 0.2 M $(NH_4)O_2SO_2O_8$/0.02 $AgNO_3$ solution in impingers 2 and 3 oxidize volatile trace metals. An additional impinger containing silica gel is used to prevent moisture from damaging the air pump. Twenty to thirty cubic meters of air are sampled during a normal sampling time of five hours.

Although the SASS sampler is one of the most extensively used systems by the EPA to screen for toxic materials, the train does have a few drawbacks. One of the major problems is that the equipment is fabricated from 316 stainless steel. Therefore, it would not be unusual to find high levels of Cr, Ni, Mo, Mn, and Fe due to leaching of the condensate and XAD-2 resin modules.

Analyses performed on stack emissions, and associated solid and liquid samples are summarized in the following flow chart (Fig. GH-1). Detailed descriptions of the analytical procedures are given later in this appendix. The procedures followed were similar to those specified in the EPA IERL-RTP Level 1 Environmental Assessment Procedures Manual (EPA-600/7-78-201).

## 4.0 Results and Discussions

The main emphasis of the Level 1 test was to screen samples for toxic materials that may be emitted from the coal fired boiler. The analytical results are presented in the following sections.

### 4.1 Particulates

Quantities of particulates collected in the SASS train cyclones and on the final filters are shown in Table GH-3. These data show that most have a diameter greater than about 10 µm. To compare emissions from other boilers, particulate loadings were calculated on a "per million Btu of heat input" basis. Because of the low residue content in the probe and cyclone rinses, further analyses on these samples were not performed.

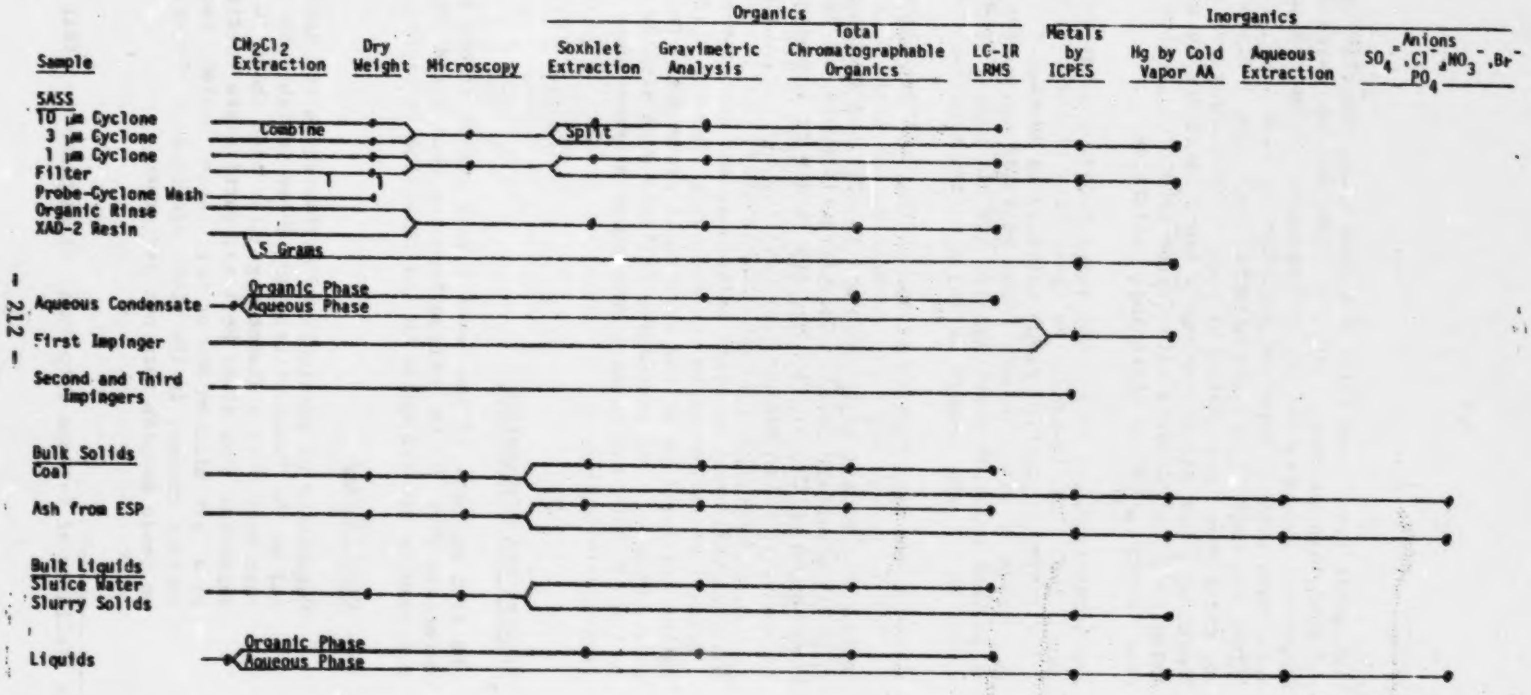
---

*See "Validity of Cyclone Cutpoints" at beginning of this appendix.

FIGURE GH-1

FLOW CHART

SUMMARY OF ANALYSIS PLAN FOR LEVEL 1 TEST



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[1] Further analyses are required if the weight is >10 percent of the total cyclone and filter sample weights. Normally the weight is much less than 10 percent.

## TABLE GH-3

## PARTICULATE MATERIAL COLLECTED IN THE CONESVILLE SASS TEST AT THE PRECIPITATOR INLET

| Sample Type | Mass (g) | % Mass | lb/MBtu[b] |
|---|---|---|---|
| Probe and cyclone rinses | 0.880 | 0.40 | 0.0378 |
| 10 μm cyclone | 169.300 | 76.6 | 7.28 |
| 3 μm cyclone | 45.0 | 20.3 | 1.93 |
| 1 μm cyclone | 5.03 | 2.27 | 0.216 |
| Final Filter[a] | | | |
| 1 | 0.273 | 0.12 | 0.0330 |
| 2 | 0.224 | 0.10 | |
| 3 | 0.264 | 0.12 | |
| 4 | 0.007 | <0.01 | |
| Total | 221. | 99.99 | 9.50[c] |

---

a. No loose particulates

b. Mass emissions per million Btu heat input (assumes that volume of gas sampled results from the combustion of 1/19.15 = 0.0522 MBtu of coal. See Example 2 in Appendix D.).

c. The total particulate loading based on this single point sample is about 50% higher than the value resulting from the Method 17 traverse (Table C-IV-3 in the main body of this report.) For total particulate loading, traverse results are considered to be more reliable than single point results.

## 4.2 Microscopy

Coal, fly ash from the precipitator hopper, the 1 μm, and the 10 + 3 μm cyclones particulates were characterized by scanning electron microscopy (SEM) and x-ray energy dispersive techniques. Typical micrographs follow documenting the morphologies observed. The size ranges and average particle diameters for the particulates are shown in Table GH-4.* The purpose of the SASS 10, 3, and 1 μm cyclones is to trap particulates ≥ 10, 10-3, and 3-1 μm in diameter respectively.* The 1 micron cyclone catch contained particulates in the expected size range. The 10 and 3 μm cyclones contained some particulates that were < 3 μm in diameter.

TABLE GH-4

ACTUAL SIZE RANGE OF CYCLONE CATCHES

| CONESVILLE | Size Range (μm) | Average (μm) |
|---|---|---|
| 1 μm cyclone* | 0.5 - 3.0 | 1.8 |
| 10 + 3 μm cyclones* | 2 - 30 | 10 |
| Fly ash | 1 - 40 | 10 |

The dominant morphology is spherical. The ESP hopper ashes have a greater departure from sphericity than the cyclone particulates and tend to have a rougher surface.

Particles exhibited various degrees of coalescence of mineral grains from the coal. Composition of these particles is dominated by silicates which were probably clays originally. The following X-ray energy spectra (Figures GH-3 through GH-6) illustrate typical compositions for each sample. Silicon, aluminum, potassium, and iron are the most abundant elements in the particulates. Calcium, sulfur, and titanium are also present. As expected, sulfur is most predominant in the coal. Also noted in the particulate samples are iron, titanium, and calcium-rich particles. These comprise at most about 10% of the collected samples. Elements detected by X-ray energy dispersive analysis are consistent with those identified by ICPES analysis discussed in the next section.

## 4.3 Metals

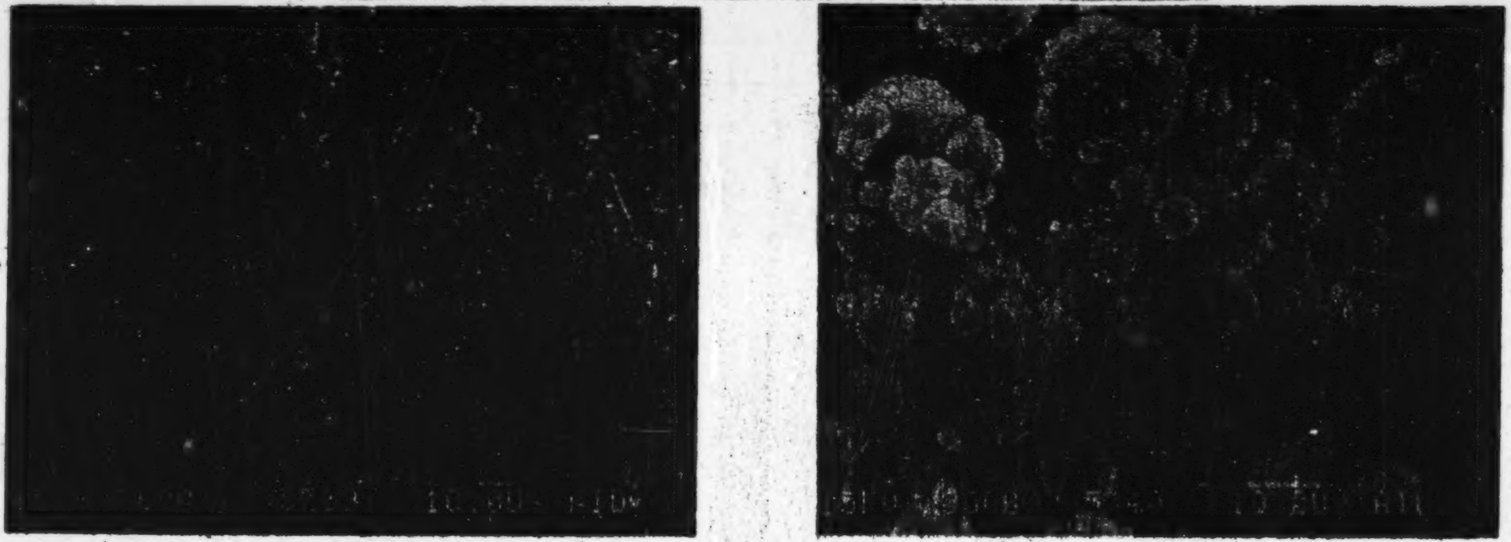
Particulate samples, final filters, XAD-2 resin, and impinger solutions were analyzed for metals using ICPES (Inductively Coupled Plasma Emission Spectroscopy). Cold vapor AA was used for the mercury analyses. Each of the four metal data tables (Tables GH-5 through GH-8) have been divided in two sections with the top half showing the elements designated on EPA's priority pollutants list for toxics in wastewater. The first such table (Table GH-5) summarizes the total metal emissions collected by the SASS. The next

---

*For additional comments on the analysis for size distribution of the particles, see "Validity of Cyclone Cutpoints" at the beginning of this appendix.

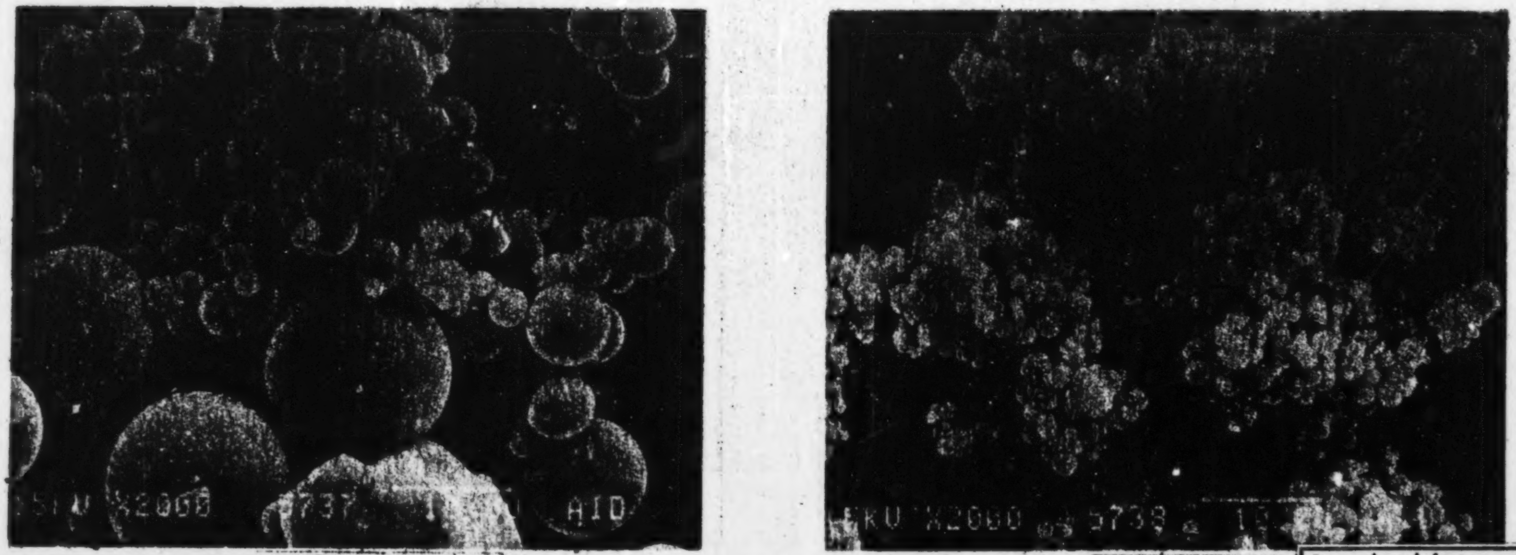
FIGURE GII-2

MICROGRAPHS OBTAINED FROM SEM ANALYSIS OF CONESVILLE SAMPLES



COAL

FLYASH



10 + 3 μm CYCLONES

1 μm CYCLONE

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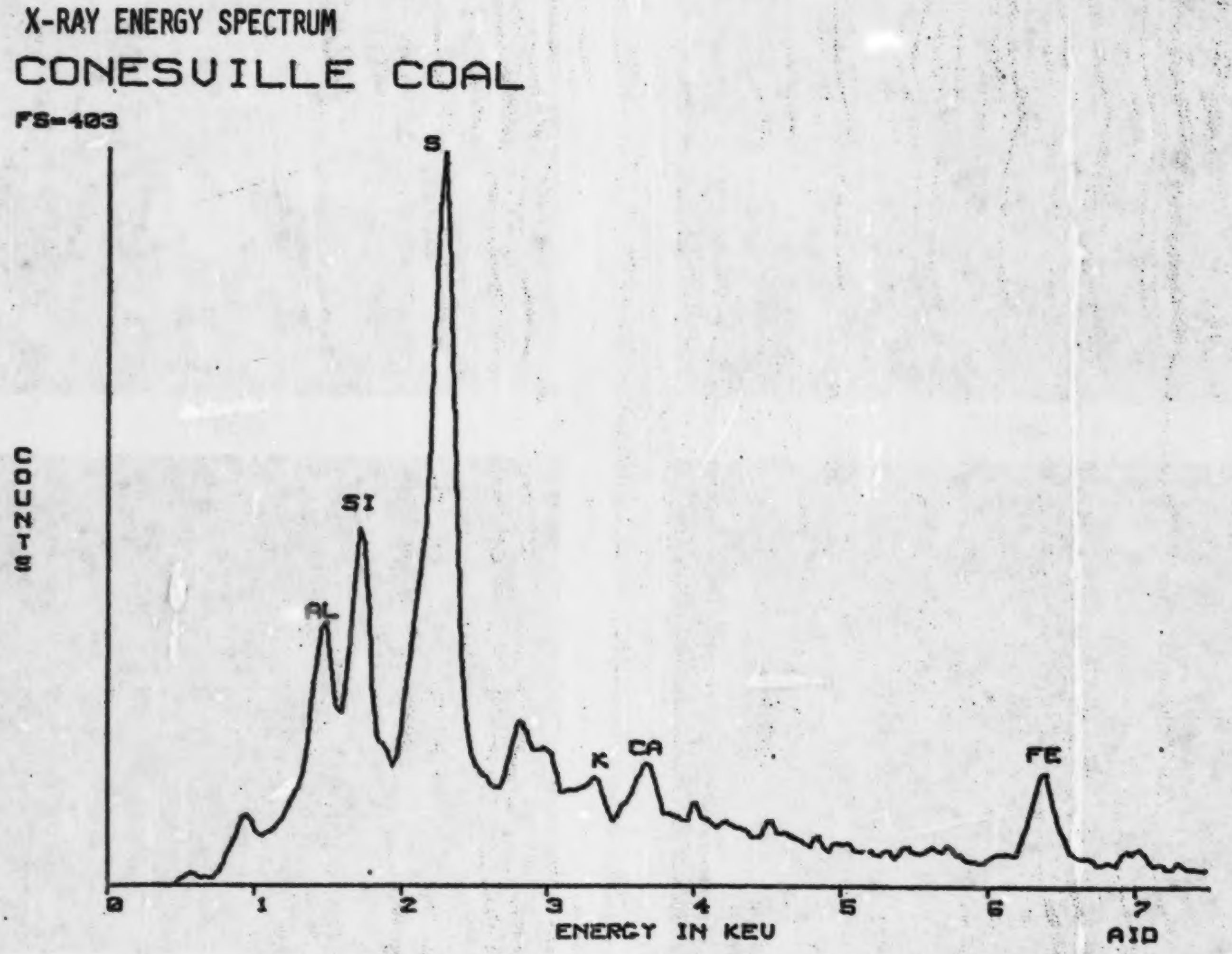


Figure GH-3

X-Ray Spectrum...Coal

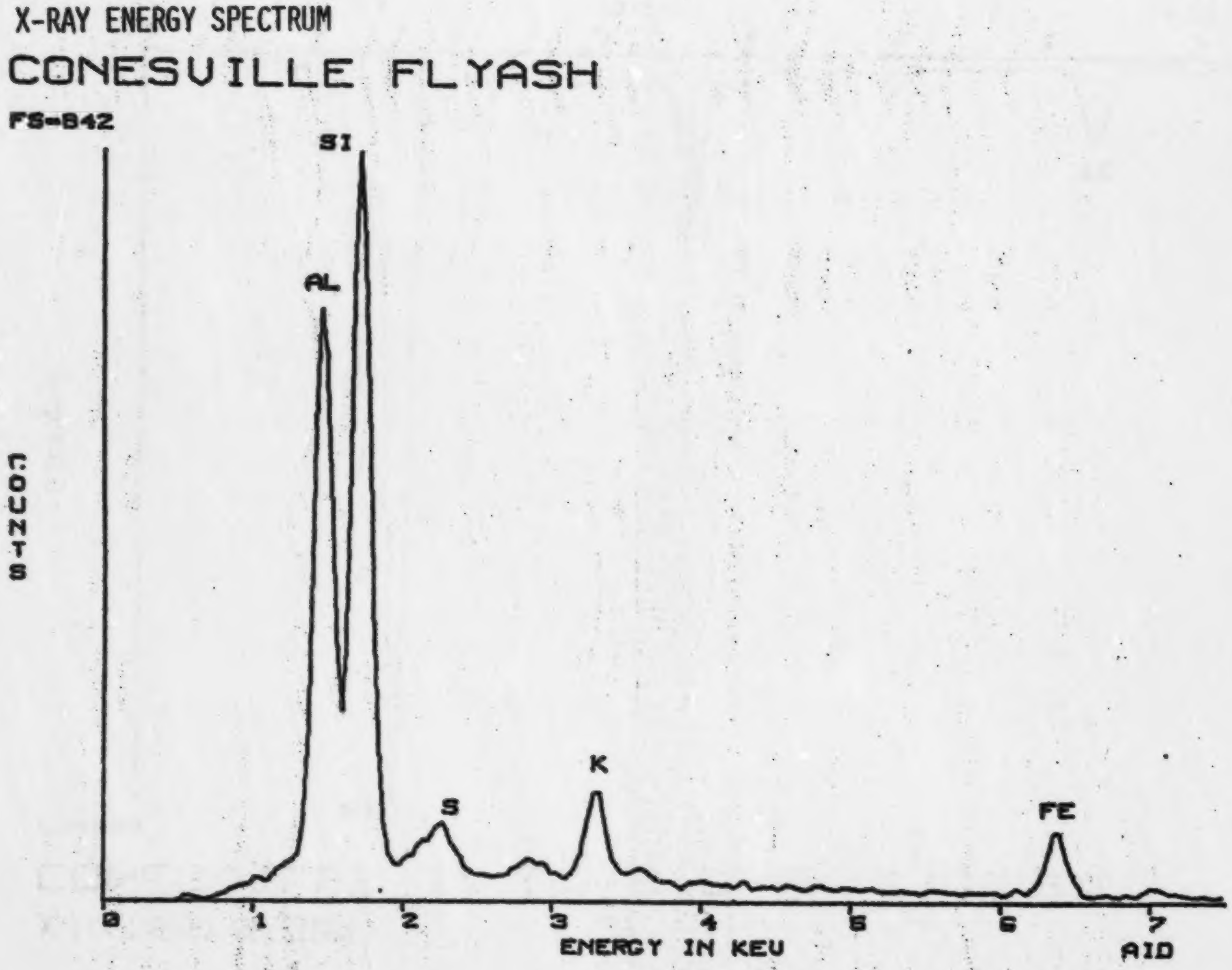


Figure GH-4

X-Ray Spectrum...Flyash
(From PPTR Hopper)

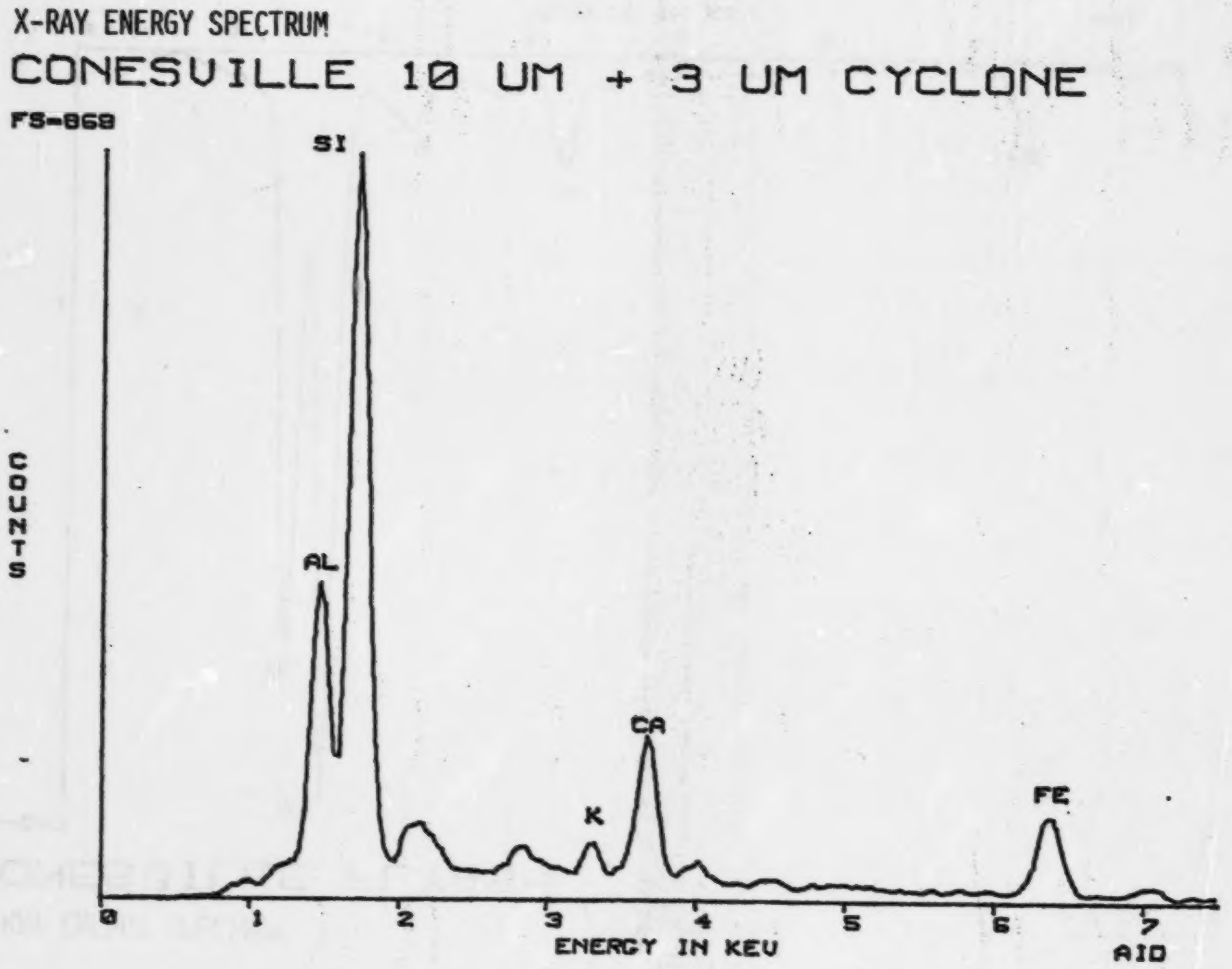


Figure GH-5

X-Ray Spectrum
10 and 3 μm cyclone

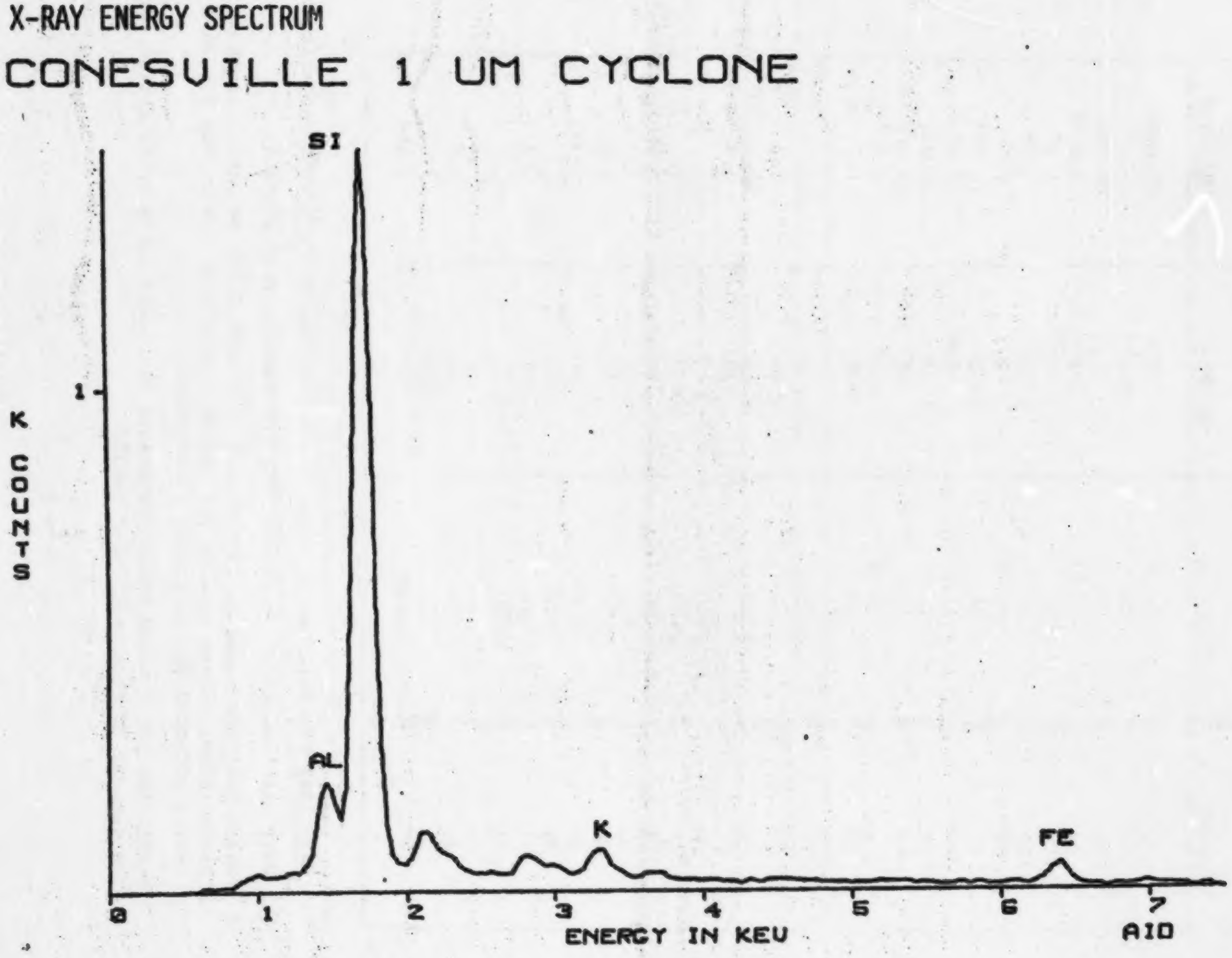


Figure GH-6

X-Ray Spectrum
1 μm Cyclone

## TABLE GH-5

## SUMMARY OF TOTAL METAL EMISSIONS FROM CONESVILLE SASS TEST

| Element | Total mg | mg/MBtu | ng/Joule |
|---|---|---|---|
| Ag | <0.44 | <8.4 | <0.0080 |
| As | 26[b] | 500[b] | 0.47[b] |
| Be | <0.14 | <2.7 | <0.0025 |
| Cd | 2.5[b] | 48[b] | 0.045[b] |
| Cr | 75 | 1400 | 1.37 |
| Cu | 58 | 1100 | 1.06 |
| Hg | 0.17 | 3.3 | 0.003 |
| Ni | 74 | 1400 | (1.3)[a] |
| Pb | (1.6)[a] | (31)[a] | (0.03)[a] |
| Sb | <2.9 | <56 | <0.053 |
| Se | 15b | 290[b] | 10.27[b] |
| Tl | 6.0[b] | 110[b] | 0.11[b] |
| Zn | 95 | 1800 | 1.7 |
| Al | 15000 | 290000 | 270. |
| Ba | 140 | 2700 | 2.5 |
| Ca | 1700 | 33000 | 31. |
| Co | 2.0 | 38 | 0.04 |
| Fe | 28000 | 540000 | 510. |
| K | 2100 | 40000 | 38. |
| Li | 23 | 440 | 0.42 |
| Mg | 660 | 13000 | 12. |
| Mn | 52 | 1000 | 0.95 |
| Mo | 19[b] | 360[b] | 0.35[b] |
| Na | 1200 | 23000 | 22. |
| P | 94 | 1800 | 1.7 |
| Si | 23000 | 440000 | 420. |
| Sn | <1.6 | <31 | <0.03 |
| Sr | 55 | 1100 | 1.0 |
| Ti | 730 | 14000 | 13. |
| V | 25[a] | 480[a] | 0.46[a] |

---

a. Data less reliable due to significant spectral or background interferences.

b. Data unreliable due to strong interferences or weak signals.

( ) Means that the value is less than 3 times the ICPES detection limit or the blank value. These results may not be significant since they are more easily affected by background fluctuations.

< Means that the printed value represents the lower limit of detection for the element in that particular sample.

## TABLE GH-6

### METAL DATA ON STACK EMISSIONS FROM CONESVILLE SASS TEST
### (RESULTS REPORTED IN μg/g)

| Element | 10 + 3 μm Cyclones | 1 μm Cyclones | Coal | Flyash | Sluice Water |
|---|---|---|---|---|---|
| Ag | <1.8 | <4.3 | <4.3 | (5.6)$^{b}$ | <0.0025 |
| As | 83$^{b}$ | 960 | (23)$^{a}$ | 220$^{a}$ | <0.0103 |
| Be | <0.43 | 4.1$^{b}$ | 12$^{b}$ | <1.1 | <0.0006 |
| Cd | 11$^{b}$ | 26$^{a}$ | <7.9 | 33$^{b}$ | <0.0047 |
| Cr | 62 | 290 | <1.3 | 92 | <0.0007 |
| Cu | 69 | 200 | 20 | 120 | <0.0002 |
| Hg | 0.0018 | 0.0088 | 0.081 | 0.014 | <0.0001 |
| Ni | 1.4 | 360 | <11 | 240 | (0.0098) |
| Pb | <7.5 | 180$^{a}$ | <13 | 110$^{b}$ | (0.0084) |
| Sb | <11 | (67)$^{b}$ | <26 | (84)$^{b}$ | (0.023)$^{a}$ |
| Se | 66$^{b}$ | 130$^{b}$ | <26 | (120)$^{b}$ | (0.021)$^{a}$ |
| Tl | 23$^{b}$ | 110$^{b}$ | <8.2 | 55$^{b}$ | <0.0048 |
| Zn | 180 | 1000 | 50 | 330 | 0.109 |
| | | | | | |
| Al | 64000 | 110000 | 15000 | 98000 | 0.20 |
| Ba | 590 | 1600 | 41 | 940 | 0.051 |
| Ca | 6800 | 1600 | 930 | 15000 | 260 |
| Co | (2.3)$^{b}$ | 38$^{a}$ | 15 | <3.8 | <0.002 |
| Fe | 130000 | 160000 | 44000 | 210000 | 0.27 |
| K | 9300 | 19000 | 1800 | 17000 | 13 |
| Li | 100 | 220 | 31 | 180 | 0.13 |
| Mg | 2900 | 6300 | 440 | 4500 | 67 |
| Mn | 200 | 490 | 26 | 330 | 0.13 |
| Mo | 66$^{b}$ | 260$^{b}$ | (18)$^{b}$ | 130$^{b}$ | (0.006) |
| Na | 1600 | 3400 | 750 | 3200 | 47 |
| P | 360 | 3000 | (85)$^{a}$ | 850 | 0.093$^{a}$ |
| Si | 100000 | 160000 | 18000 | 180000 | 0.21 |
| Sn | <5.7 | 60$^{b}$ | <13 | <15 | <0.0078 |
| Sr | 240 | 500 | 24 | 400 | 0.57 |
| Ti | 3300 | 5900 | 440 | 5100 | 0.029 |
| V | 110$^{a}$ | 380 | (13)$^{a}$ | 170$^{a}$ | <0.0045 |

a Data less reliable due to significant spectral or background interferences.

b Data unreliable due to strong interferences or weak signals.

( ) Means that the value is less than 3 times the ICPES detection limit or the blank value. These results may not be significant since they are more easily affected by background fluctuations.

< Means that the printed value represents the lower limit of detection for the element in that particular sample.

## TABLE GH-7

### METAL DATA ON STACK EMISSIONS FROM CONESVILLE SASS TEST
(Results Reported In Total mg Collected)

| Element | 10 & 3 µm Cyclones | 1 µm Cyclone | Final Filters | XAD-2 Resin | Impinger 1+ Condensate | Imp 2 + 3 |
|---|---|---|---|---|---|---|
| Ag | <0.39 | <0.02 | $(0.003)^{b}$ | <0.018 | <0.008 | |
| As | $18^{b}$ | 4.8 | 3.0 | <0.076 | $0.10^{a}$ | <0.0058 |
| Be | <0.092 | $0.021^{b}$ | $0.005^{b}$ | <0.005 | $<0.019^{b}$ | |
| Cd | $2.3^{b}$ | $0.13^{a}$ | $(0.008)^{b}$ | <0.034 | $0.079^{b}$ | |
| Cr | 13 | 1.5 | 0.052 | 1.7 | 59 | |
| Cu | 15 | 1.0 | 0.11 | 1.4 | 40 | |
| Hg | 0.00039 | 0.00004 | | | 0.053 | 0.120 |
| Ni | 29 | 1.8 | 0.036 | <1.6 | 43 | |
| Pb | <1.6 | $0.91^{a}$ | (0.016) | <0.23 | 0.64 | |
| Sb | <2.4 | $(0.34)^{b}$ | <0.012 | <0.11 | $(0.073)^{b}$ | <0.0062 |
| Se | $14^{b}$ | $0.67^{b}$ | <0.008 | <0.076 | $0.18^{b}$ | |
| Tl | $4.9^{b}$ | $0.57^{b}$ | $0.032^{b}$ | $(0.067)^{a}$ | $0.47^{b}$ | |
| Zn | 38 | 5.0 | 0.064 | <2.2 | 52 | |
| Al | 14000 | 560 | 16 | <0.59 | 2.0 | |
| Ba | 130 | 8.1 | 1.5 | 0.23 | 0.15 | |
| Ca | 1500 | 81 | 77 | (2.1) | 15 | |
| Co | $(0.49)^{b}$ | $0.19^{a}$ | $(0.003)^{a}$ | 0.058 | 1.3 | |
| Fe | 27000 | 780 | 7.2 | 11 | 310 | |
| K | 2000 | 94 | 1.1 | 0.9 | <0.03 | |
| Li | 22 | 1.1 | 0.021 | <0.006 | <0.001 | |
| Mg | 620 | 32 | 5.4 | <1.1 | 1.1 | |
| Mn | 42 | 2.5 | 0.034 | 0.19 | 7.0 | |
| Mo | $14^{b}$ | $1.3^{b}$ | 0.24 | <0.21 | $3.8^{a}$ | |
| Na | 340 | 17 | 1.5 | <4.0 | 850 | |
| P | 77 | 15 | 1.6 | <0.47 | $(0.061)^{b}$ | |
| Si | 22000 | 810 | 0.72 | <0.035 | $0.24^{a}$ | |
| Sn | <1.2 | $0.30^{b}$ | <0.006 | <0.058 | <0.026 | |
| Sr | 52 | 2.5 | 0.18 | <0.013 | 0.022 | |
| Ti | 700 | 29 | 0.57 | <0.37 | $0.041^{a}$ | |
| V | $22^{a}$ | 1.9 | 0.22 | <0.033 | 0.38 | |

---

a Data less reliable due to significant spectral or background interferences.

b Data unreliable due to strong interferences or weak signals.

( ) Means that the value is less than 3 times the ICPES detection limit or the blank value. These results may not be significant since they are more easily affected by background fluctuations.

< Means that the printed value represents the lower limit of detection for the element in that particular sample.

## TABLE GH-8

### METAL DATA ON BLANKS FROM CONESVILLE SASS TEST (Results Reported in Total mg Per Test)

| Element | XAD-2 | Impinger 1 | Impingers 2 + 3 |
|---|---|---|---|
| Ag | <0.021 | 0.0077 | 110 |
| As | <0.086 | 0.015 | (0.0058) |
| Be | <0.0049 | <0.00026 | 0.0034[b] |
| Cd | <0.039 | <0.0021 | 0.0091[a] |
| Cr | 0.091 | 0.015 | 1.3 |
| Cu | 0.43 | <0.000086 | 0.11 |
| Hg |  | <0.00004 | <0.00003 |
| Ni | 3.9 | (0.0070) | 1.0 |
| Pb | 0.43 | (0.0046) | 0.014 |
| Sb | <0.13 | <0.0070 | (0.0089)[b] |
| Se | (0.099)[b] | (0.0074)[a] | <0.0033 |
| Tl | <0.040 | <0.0022 | 0.0097[b] |
| Zn | 2.3 | 0.046 | 0.28 |
| Al | 0.96 | 0.039 | 0.26 |
| Ba | 0.071 | 0.012 | 0.012 |
| Ca | 2.0 | 0.41 | 1.0 |
| Co | <0.017 | <0.00091 | 0.030 |
| Fe | 2.2 | 0.11 | 7.7 |
| K | (0.13) | <0.0045 | 0.80 |
| Li | 0.0057 | <0.000086 | 0.00062 |
| Mg | 2.2 | 0.47 | 0.47 |
| Mn | 0.045 | <0.000086 | 0.15 |
| Mo | 0.21 | 0.0075 | 0.12 |
| Na | 4.5 | 1.08 | 3.4 |
| P | 0.72 | (0.018) | 0.035 |
| Si | 0.036 | 0.062 | 0.014 |
| Sn | <0.065 | <0.0036 | <0.0025 |
| Sr | 0.014 | 0.0019 | 0.0019 |
| Ti | 0.54 | 0.020 | 0.055 |
| V | (0.080) | (0.0057) | <0.0014 |

a. Data less reliable due to significant spectral or background interferences.

b. Data unreliable due to strong interferences or weak signals.

( ) Means that the value is less than 3 times the ICPES detection limit or the blank value. These results may not be significant since they are more easily affected by background fluctuations.

< Means that the printed value represents the lower limit of detection for the element in that particular sample.

two tables (GH-6 and GH-7) show the distribution of metals among the Level 1 samples and are followed by Table GH-8 showing metal concentrations in the blanks. The tables show that most (largest mass of) metals are present in the particulates, and as expected, mercury was found at higher levels in the impinger samples.

The second and third impingers are used to entrap volatile elements, namely As, Hg, and Sb. This was accomplished by oxidative dissolution of these elements using a solution of ammonium persulfate and silver nitrate. The data show that except for mercury, other volatile metals were at or near their detection limits (< 100 mg/SASS test).

Because the SASS train is fabricated from 316 stainless steel, high levels of Fe, Ni, Mn, Mo, and Cr are not unusual. The acid content of the gases would influence the amount of metals leached from the sample walls.

Metals results on stack emissions are consistent with material found in the fly ash. Metals appear to be more concentrated on the 1 μm cyclone catch and fly ash samples than on the 10 and 3 μm cyclone catches and coal samples. This is probably due to unburned carbon on the larger particles. Total stack emissions show that most (greatest mass of) metals are contained in the 10 + 3 μm particles. The associated water samples contained very low metal levels.

## 4.4 Anions

Bulk coal and fly ash (from the precipitator hopper) samples were water-extracted and analyzed for anions using ion chromatography according to Figure GH-7, showing the analysis scheme for bulk solids and liquids. (Figure GH-8 shows the analysis scheme for the flue gas and entrained particles.) The results (Table GH-9) show that only low concentrations of extracted sulfate were measured. Bulk water samples collected during the SASS train tests were also analyzed. Chloride and sulfate were measured in the liquid sample. These liquid test results are included with the coal and fly ash extraction results (Table GH-9).

TABLE GH-9

ANION ANALYSIS OF SOLIDS AND LIQUID SAMPLES

| Sample | Cl- | $PO_4^{3-}$ | Br- | $NO_3^-$ | $SO_4^{2-}$ |
|---|---|---|---|---|---|
| Solids (wt% $H_2O$ extracted) | | | | | |
| Conesville Coal | <0.05 | <0.1 | <0.1 | <0.1 | 1.1 |
| Conesville Fly Ash (from ESP hopper) | <0.05 | <0.1 | <0.1 | <0.1 | 2.0 |
| Liquids ( g/mL) | | | | | |
| Conesville Water | 83 | <10 | <10 | <10 | 690 |

FIGURE GH-7

ANALYSIS SCHEME FOR BULK SOLIDS AND LIQUIDS

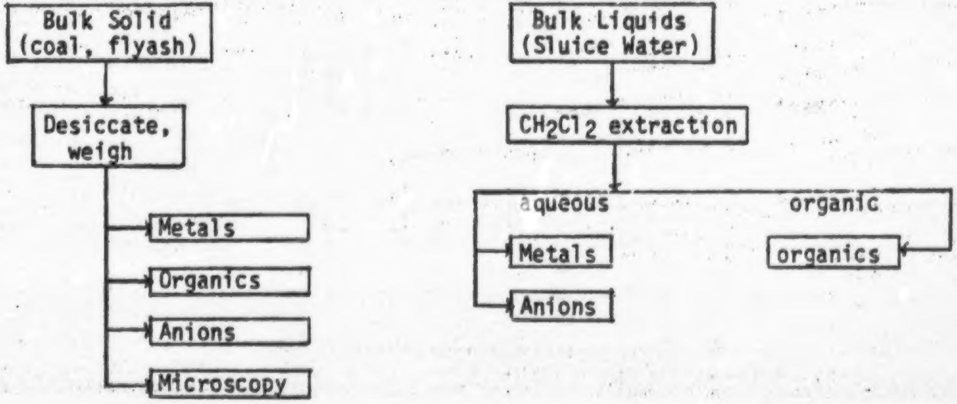
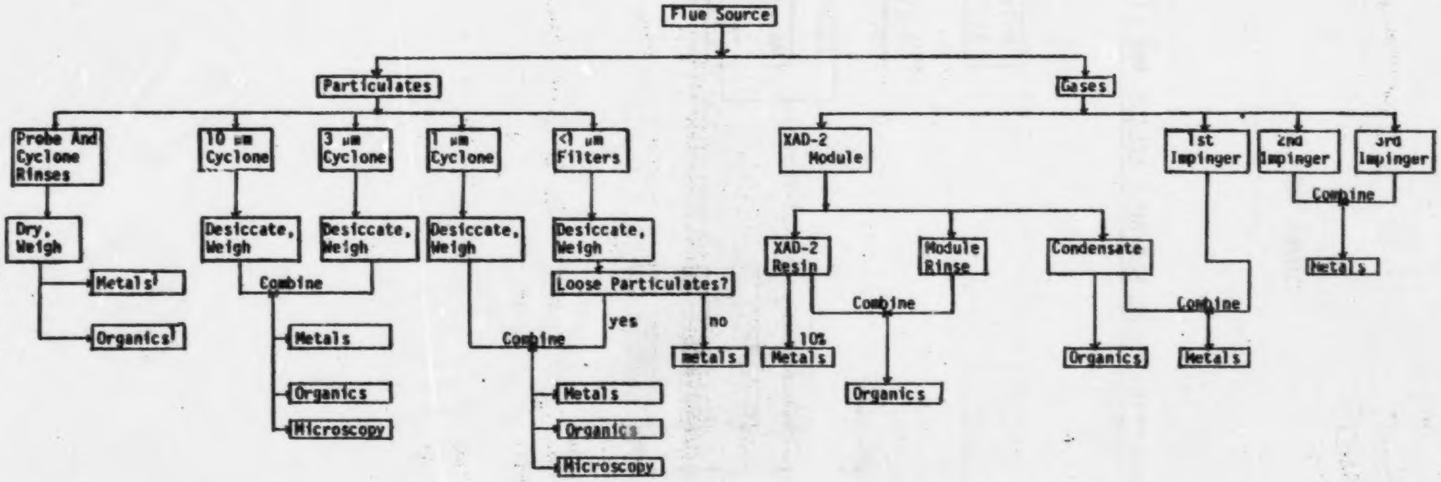


FIGURE GH-8

Analysis Scheme For Flue Gases And Particulates



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[1] Analyzed when >10% of the particulate catch.

## 4.5 Organics

Amounts of organics extracted from the SASS particulates and XAD-2 resin were measured by gravimetric and gas chromatographic techniques. When there were sufficient quantities, a silica gel separation scheme was used to isolate compound classes. Infrared and mass spectrometry were used to identify classes and specific compounds. The flow charts (Figs. GH-8 and GH-9) show the analytical scheme and methodology.

Gravimetric and total chromatographable organics (TCO) data on the concentrated extracts are shown on Table GH-10. Data presented in these tables are based on the total SASS sample, not just the fraction used in the analysis.* The EPA Level 1 protocol specifies that if the sum of the total extractable organics is > 15 mg, the extract should be further characterized using a silica gel separation scheme to isolate compound classes. Only the SASS XAD-2 resin extracted required further separations. Because the particulates were held at 400°F during sampling, it was not unexpected that most organics condensed onto the XAD-2 adsorbent that was chilled to <70°F. Silicic acid column chromatography was also performed on the coal extracts.

Quantities of organics isolated after silica gel separation of the XAD-2 and coal extracts are shown on Table GH-11. The table shows that most compounds in the XAD-2 extracts were isolated mostly in fraction 6 for the Conesville sample, and that organic distributions in the coal extracts were evenly spread over the seven silica gel fractions.

The Fourier transform infrared (FTIR) method was used to analyze for major functional groups. Based on the EPA protocol, a listing of the major peaks and possible assignments are given in Tables GH-12 through GH-19 (one table for each cut, and blank). Intensities are reported relative to the strongest peak in the spectrum (S = strong, 70-100%; M = medium, 30-70%; W = weak, <30%). Major compounds in the XAD-2 fraction 6 were alkyl esters. However, similar compounds were observed in the unseparated methylene chloride extract of a blank XAD-2 sample.

Because most compounds were in cut 6 for Conesville, this fraction was analyzed by GC/MS. Also, organics extracted from the Conesville blank XAD-2 were analyzed by probe MS. Two major components were found in the XAD-2 blank. They were identified as dioctyl esters of adipic and phthalic acids as indicated in Figures GH-10 and GH-11. Phthalate and adipate contaminants in the XAD-2 extracts are consistent with the FTIR data.

Figure GH-12 is a reconstructed ion chromatogram of Cut 6 from the XAD-2 fractions. Major components in Conesville Cut 6 are aliphatic acids, assuming all the adipates and phthalates are from the XAD-2 resin blank.

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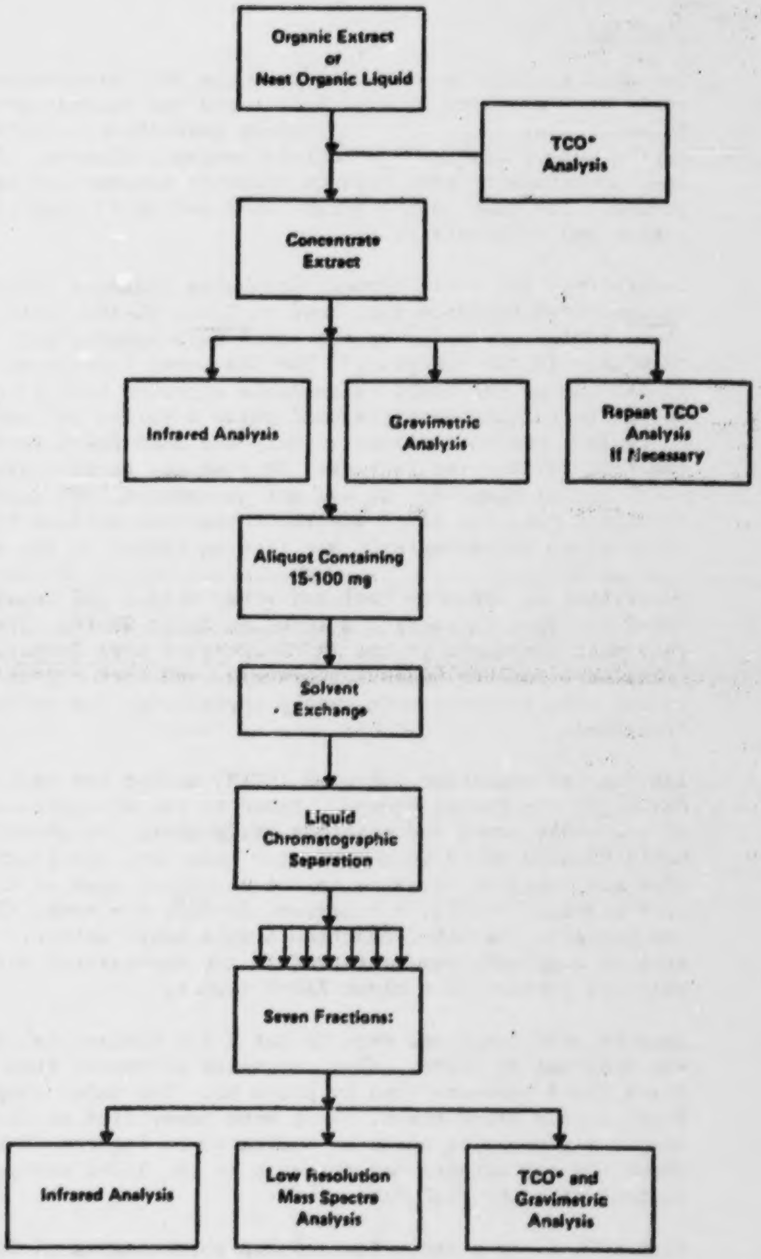
*Because the background level of organics in the XAD-2 (Table GH-10) is so large, the final results may contain a large error bar.



*if <40 mg/l

FIGURE GH-9. Organic analysis methodology.

## TABLE GH-10

## MASS OF EXTRACTABLE ORGANICS FROM CONESVILLE SASS TEST

| Sample Type | Gravimetric | TCO | Total (mg/test) |
|---|---|---|---|
| 10 + 3 μm cyclones | 4.8 | — | 4.8 |
| 1 μm cyclone | <3.5 | — | <3.5 |
| XAD-2 Resin (uncorrected) | 48.9 | 1.5 | 50.4 |
| Blank XAD-2[a] | 26.9 | 0.7 | 27.6 |
| XAD-2 (corrected for blank) | 22.0 | 0.8 | 22.8 |
| Condensate | <0.2 | <0.2 | <0.2 |
| Coal (mg/g)[b] | 9.03 | 0.74 | 9.77 |
| Flyash (mg/g)[c] | <0.01 | <0.01 | <0.01 |
| Water (mg/L)[d] | 0.54 | 0.04 | 0.58 |

[a] For this test, the background concentration of organics in the XAD-2 blank was unusually high. Therefore, the organic data from the XAD-2 analysis in this report may contain a wide error bar.

[b] 83.52 g extracted

[c] 100.80 g extracted

[d] 3.69 L extracted

Table GH-11

## MASS OF EXTRACTABLE ORGANICS SEPARATED ON SILICA GEL FOR CONESVILLE SASS TEST

| Silica Gel Fraction | XAD-2 (mg/SASS Test)[a] | | | Coal (mg/g)[b] | | |
|---|---|---|---|---|---|---|
| | Grav. | TCO | Total | Grav. | TCO | Total |
| 1 | 5.6 | 0.2 | 5.8 | 0.74 | 0.24 | 0.98 |
| 2 | 0.8 | <0.1 | 0.8 | 0.46 | 0.31 | 0.77 |
| 3 | 1.4 | <0.1 | 1.4 | 2.51 | 0.80 | 3.31 |
| 4 | 1.7 | <0.1 | 1.7 | 1.26 | 0.05 | 1.31 |
| 5 | 1.7 | <0.1 | 1.7 | 0.95 | 0.04 | 0.99 |
| 6 | 33.4 | 1.1 | 34.5 | 3.03 | 0.05 | 3.08 |
| 7 | 7.9 | 0.2 | 8.1 | 0.09 | <0.01 | 0.09 |
| TOTAL | 52.5 | 1.5 | 54.0 | 9.04 | 1.49 | 10.53 |

a Portion used for the LC separation was 35.2 mg of 50.4 mg sample (Table GH-10). Results are computed for the total sample with no correction for the background concentration in the blank.

b Portion used for LC separation was 7.82 mg of the 9.77 mg sample (Table GH-10). Results are computed for the total sample.

Table GH-12

## CONESVILLE SASS XAD-2 COLUMN CUT NO. 1

Major Peaks and Assignments

| $cm^{-1}$ | Intensity | Assignment |
|---|---|---|
| 2954 | M | aliphatic CH |
| 2920 | S | aliphatic CH |
| 2850 | M | aliphatic CH |
| 1462 | W | aliphatic CH |
| 1378 | W | aliphatic CH (methyl) |
| 728, 720 | W | Aliphatic $CH_2$, long chain |

Other Remarks:

Very weak absorptions at 1740 and 1240 due to minor ester component.

Table GH-13

## CONESVILLE SASS XAD-2 COLUMN CUT NO. 2

Major Peaks and Assignments

| $cm^{-1}$ | Intensity | Assignment |
|---|---|---|
| 2956 | M | aliphatic CH |
| 2920 | S | aliphatic CH |
| 2850 | M | aliphatic CH |
| 1740 | W | ester C=O |
| 1463 | W | aliphatic C-H |
| 1378 | W | aliphatic (methyl) |
| 1242 | W | ester C-O-C |
| 728, 720 | W | aliphatic $CH_2$ long chain |

Other Remarks:

Ester is probably an acetate.

Table GH-14

## CONESVILLE SASS XAD-2, COLUMN CUT 3

Major Peaks and Assignments

| $cm^{-1}$ | Intensity | Assignment |
|---|---|---|
| 2952 | M | aliphatic CH |
| 2918 | S | aliphatic CH |
| 2845 | S | aliphatic CH |
| 1736 | W | ester C=O |
| 1452 | W | aliphatic CH |
| 1378 | W | aliphatic CH (methyl) |
| 1365 | W | $CH_3$ of methyl ester |
| 1260 | W | $Si-CH_3$ |
| 1240 | W | ester C-O-C |
| 1100, 1020 | W | Si-O-C and Si-O-Si |
| 800 | W | Si-C |
| 728, 718 | W | $CH_2$ long chain |

Unassigned weak bands
1630, 1560, 1510, 1345, 1170, 758

Other Remarks:

- Silicon lubricant contamination.
- Several of weak bands also appear in cut 4 and may be due to aryl nitro compound.

Table GH-15

## CONESVILLE SASS XAD-2, COLUMN CUT NO. 4

Major Peaks and Assignments

| $cm^{-1}$ | Intensity | Assignment |
|---|---|---|
| 3355 | W | NH or OH |
| 2950 | M | aliphatic CH |
| 2918 | S | aliphatic CH |
| 2845 | M | aliphatic CH |
| 1735 | M | ester C=O |
| 1512 | M | aryl $NO_2$ (?) |
| 1462 | W | aliphatic CH |
| 1365 | W | $CH_3$ of methyl ester |
| 1345 | W | aryl $NO_2$ (?) |
| 728, 718 | W | $CH_2$ long chain |

Unassigned weak bands
1630, 1563, 1263, 1248, 1168, 1100, 1076, 1010, 970, 820, 762, 755, 700

Other Remarks:

- Low levels of silicon lubricant may contribute to 1263, 1100, 1010, 820 bands.
- Many of weak bands are also present in cut 3, and may be due to aromatic nitro or aromatic amine compounds.

Table GH-16

## CONESVILLE SASS XAD-2, COLUMN CUT NO. 5

Major Peaks and Assignments

| $cm^{-1}$ | Intensity | Assignment |
|---|---|---|
| 3440, 3340 | W | broad; NH or OH |
| 2954 | M | aliphatic CH |
| 2920 | S | aliphatic CH |
| 2857 | M | aliphatic CH |
| 1732 | M | ester C=O |
| 1600 | W | aromatic |
| 1462 | M | aliphatic CH |
| 1380 | M | aliphatic CH (methyl) |
| 1365 | W | $CH_3$ of methyl ester |
| 1270 | M | C-O |
| 1200-1000 | M | broad multiplet; various C-O |
| 745 | W | aromatic CH |
| 730, 720 | W | aliphatic $CH_2$ long chain |
| 701 | W | aromatic |

Unassigned weak bands
1630, 1555, 1510, 1338, 970, 802

Table GH-17

## CONESVILLE SASS XAD-2, COLUMN CUT NO. 6

Major Peaks and Assignments

| $cm^{-1}$ | Intensity | Assignment |
|---|---|---|
| 3600-2400 | W | broad; OH |
| 2950 | M | shoulder; aliphatic CH |
| 2918 | S | aliphatic CH |
| 2846 | S | aliphatic CH |
| 1730 | M | ester C=O |
| 1710 | M | acid C=O |
| 1597 | W | aromatic |
| 1462 | M | aliphatic CH |
| 1378 | W | aliphatic CH (methyl) |
| 1365 | W | $CH_3$ of methyl ester |
| 1300-1000 | M | broad multiplet; various C-O |
| 720 | W | aliphatic $CH_2$ long chain |

Unassigned weak bands
1555, 1518, 1500, 1415, 1338, 755

Table GH-18

## CONESVILLE SASS XAD-2, COLUMN CUT NO. 7

Major Peaks and Assignments

| $cm^{-1}$ | Intensity | Assignment |
|---|---|---|
| 3600-2300 | W | broad; OH |
| 2950 | M | aliphatic CH |
| 2915 | S | aliphatic CH |
| 2845 | S | aliphatic CH |
| 1730 | M | ester C=O |
| 1715 | M | shoulder; acid C=O |
| 1462 | M | aliphatic CH |
| 1380 | W | aliphatic CH (methyl) |
| 1300-1000 | M | broad multiplet; various C-O |
| 720 | W | aliphatic $CH_2$ long chain |

Unassigned weak bands
1555, 1410, 955, 755

Table GH-19

## XAD-2 BLANK

Major Peaks and Assignments

| $cm^{-1}$(1) | Intensity | Assignment |
|---|---|---|
| 2958, 2920 | S | aliphatic C-H |
| 2864, 2858 | M | aliphatic C-H |
| 1732 | S | ester C=O |
| 1600 | W | aromatic |
| 1452 | M | aliphatic C-H |
| 1378 | W | aliphatic C-H (methyl) |
| 1300-950 | S | broad multiplet; various C-O |
| 795,702 | W | aromatic |

Unassigned weak bands
1585, 1508, 1485, 905, 830

Other Remarks:

Material appears to be highly oxygenated, possibly polyether and/or polyester.

---

(1) Frequencies are to ± 1 $cm^{-1}$ in the 2000-450 $cm^{-1}$ region and to ± 3 $cm^{-1}$ between 3800 and 2000 $cm^{-1}$.

MASS SPECTRUM
05/20/81 13:54:00 + 4:29
SAMPLE: 8866-9-1 XAD-2 BLANK

DATA: 810544 #69
CALI: MAY20C #2

BASE M/E: 129
RIC: 532480.

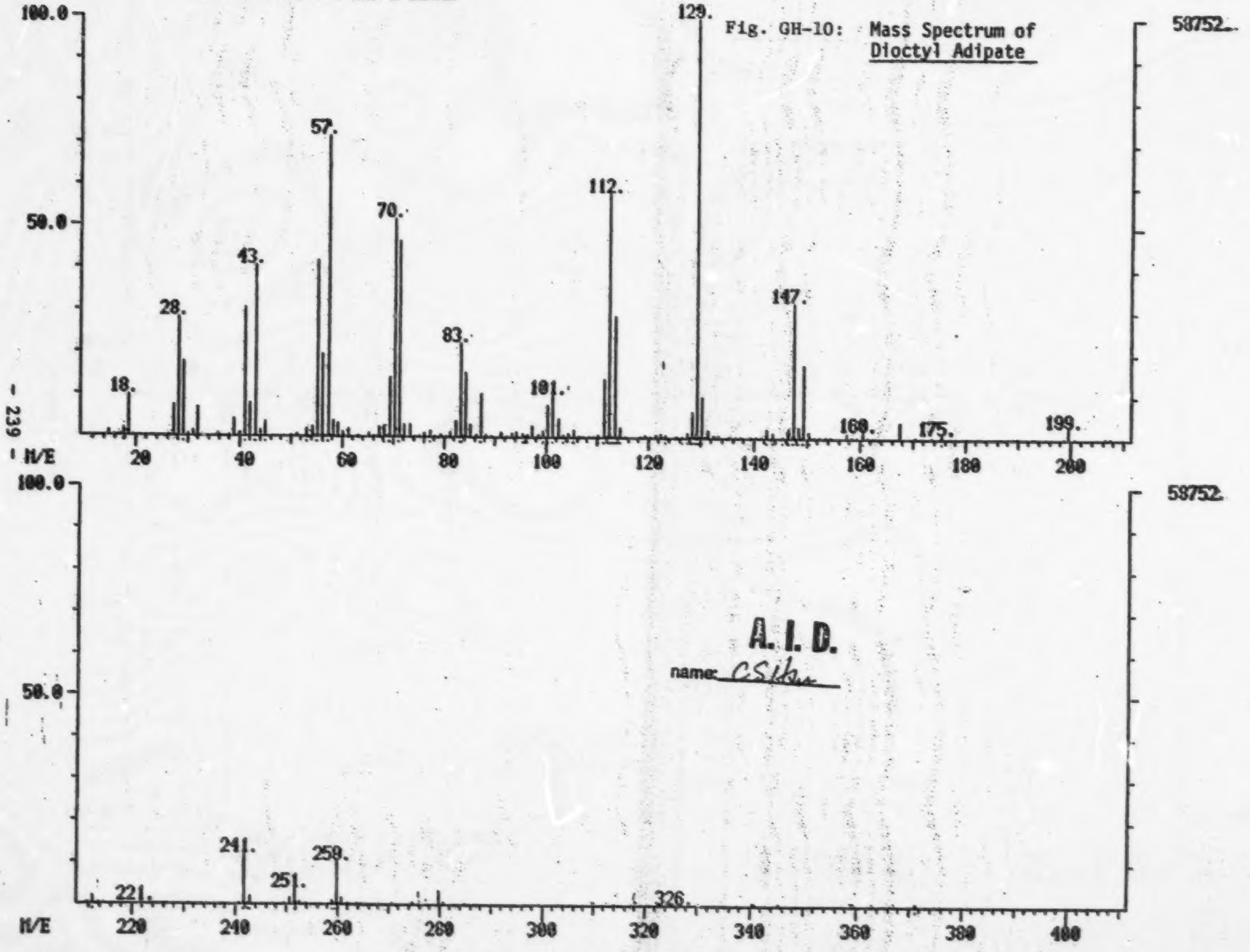
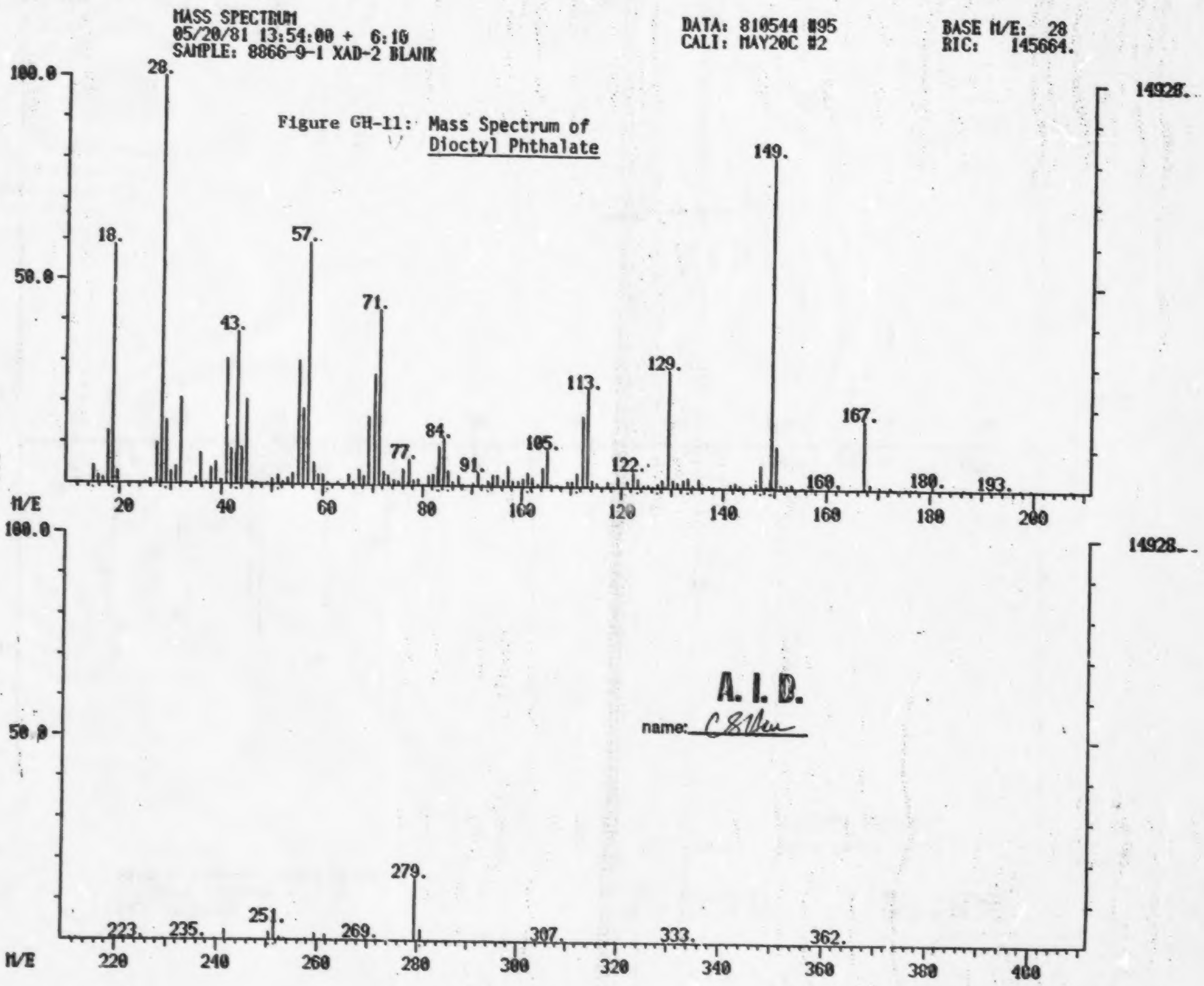


Fig. GH-10: Mass Spectrum of Dioctyl Adipate

A. I. D.
name: CSilva

Figure GH-11: Mass Spectrum of Dioctyl Phthalate



A. I. D.
name: C 8 Ven

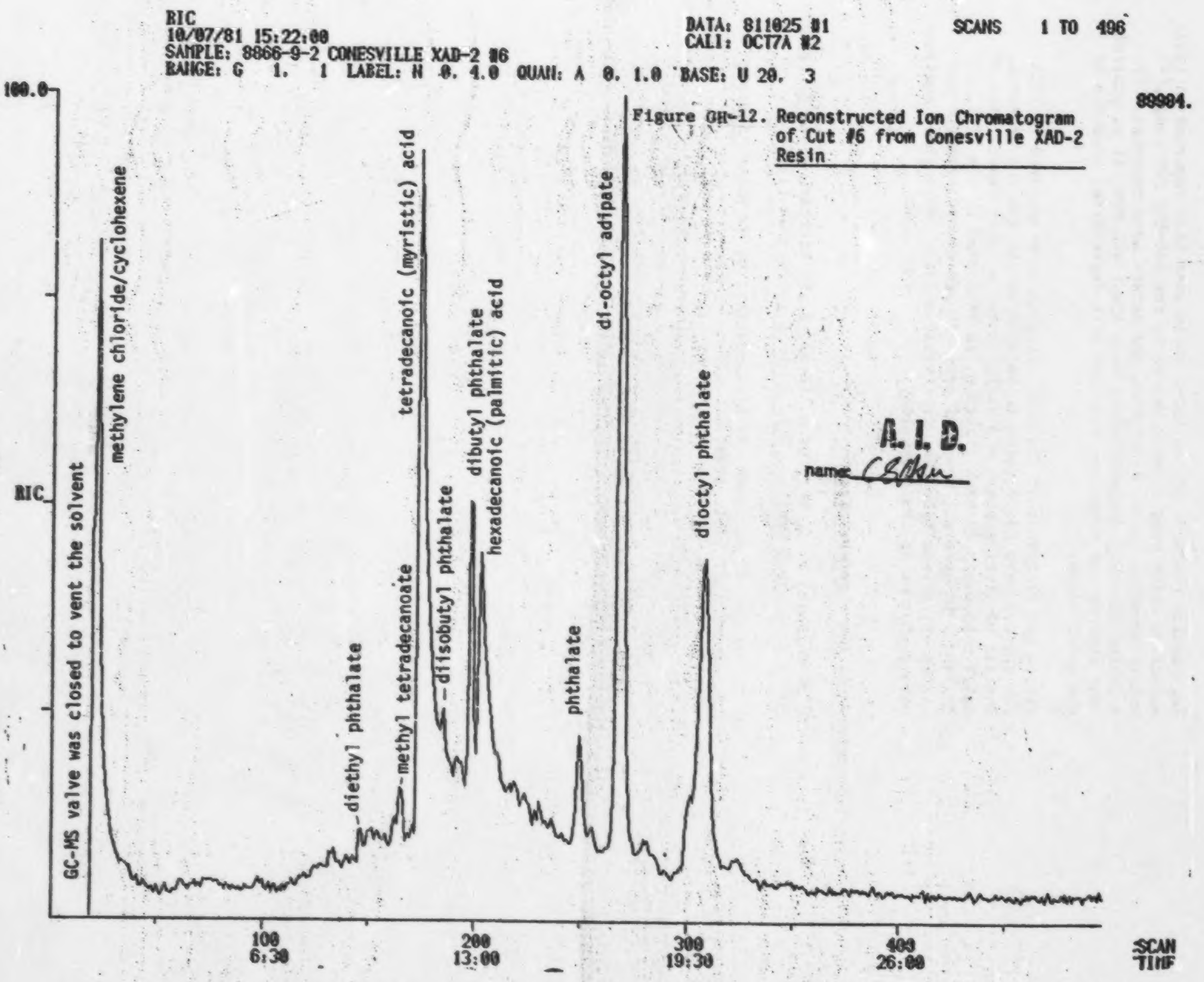


Figure GH-12. Reconstructed Ion Chromatogram of Cut #6 from Conesville XAD-2 Resin

A. I. D.
name CBAkin

Degradation products of the XAD-2 resin have been reported in stack emissions containing nitrous oxides in the 460-810 PPM range.(2) Mainly aromatic acids, aldehydes, and esters were reported. Considering that $NO_x$ concentrations were about 400 PPM, it is possible that some of the compounds detected were degradation products of the XAD-2 resin.

Silica gel fractions of the coal extracts were analyzed by FTIR. The spectra were too complex to be analyzed by the EPA protocol. Instead of listing peaks and assignments, a brief description of major components in each fraction, as indicated by the FTIR, follows. In general, the coal extracts are highly aromatic and highly oxygenated (phenols, carboxylic acids). No further analyses were performed on these samples.

## 5.0 References for this Appendix

1. D. J. Eatough, M. C. Lee, D. W. Later, B. E. Richter, N. L. Eatough, and L. D. Hansen, Environ. Sci. Technol., 15, 1502 (1981).

2. R. L. Hanson, C. R. Clark, R. L. Carpenter, C. H. Hobbs, Environ. Sci. Technol., 6, 701, (1981).

## FTIR ANALYSIS OF COAL FRACTIONS

- Conesville Coal Extract Before LC Column Separation

The coal extract is a highly aromatic, highly oxygenated material. Phenolic material is present as indicated by the broad OH stretch maximizing at 3350 cm$^{-1}$ and the broad C-O stretch maximizing near 1250 cm$^{-1}$. Carboxylic acids are indicated by the 1690 cm$^{-1}$ carbonyl. Amides are suggested by a 1640 carbonyl. Aliphatic absorptions are observed at 2957, 2920, 2860 cm$^{-1}$, and at 1455 and 1378 cm$^{-1}$. Aromatic absorptions are observed at 1605 cm$^{-1}$ (broad), 3050, 3020, 870, 812, and 748 cm$^{-1}$. There appear to be little mono-substituted aromatics present, most rings having two or more substituents.

- Conesville LC Cut 1

Cut 1 consists almost exclusively of long chain paraffins absorbing at 2950, 2920, 2850, 1460, 1378, 730, and 720 cm$^{-1}$.

- Conesville LC Cut 2

Cut 2 consists of long chain paraffins and minor amounts of aromatics. The aromatics absorb at 3050, 1600, 870, 810, and 750 cm$^{-1}$.

- Conesville LC Cut 3

Cut 3 consists of alkyl aromatics. Aromatic absorptions at 3050, 3020, 1603, 876, 812, and 749 cm$^{-1}$ are prominent. 2958, 2922, 2847, 1455, and 1378 cm$^{-1}$ absorptions due to alkyl groups (aromatic side chain or paraffin) are observed. Little or no mono-substituted aromatics are present.

- Conesville LC Cut 4

Cut 4 is highly aromatic, exhibiting aromatic absorptions similar to those described above. Aliphatic absorptions are also observed. Phenolics are present as indicated by a broad OH absorption centered at 3350 cm$^{-1}$ and by a broad C-O band at 1250 cm$^{-1}$. Carboxylic acids are indicated by a 1690 cm$^{-1}$ carbonyl.

- **Conesville LC Cut 5**

  Cut 5 is similar to cut 4. The concentration of phenolics is slightly higher in cut 5 than in cut 4.

- **Conesville LC Cut 6**

  Cut 6 is composed principally of phenolic compounds. The concentration of phenolics is higher than in cut 4 or 5. Carboxylic acids are indicated by a carbonyl absorption at 1690 $cm^{-1}$. A 1640 $cm^{-1}$ carbonyl is observed, which may be due to amides or conjugated ketones (quinone).

- **Conesville LC Cut 7**

  Cut 7 has a somewhat lower concentration of phenolics than cut 6. The carbonyl-containing species (1695 $cm^{-1}$ and 1645 $cm^{-1}$ C+O) are more prominent in this fraction.

# APPENDIX I

## Acurex SASS and Level 1 Data
## (Summary of Acurex Results at Precipitator Outlet)

While the Level 1 test was being performed, simultaneous complementary testing was performed by Acurex Corporation under a separate EPA contract. Acurex agreed to exchange data with ER&E. The author wishes to thank Mr. Carlo Castaldini and the staff of Acurex Corporation for the advanced copy of this data in support of this report.

The following data were selected from that advanced copy.

During the test, a controlled condensation train was used for $SO_x$ testing and showed 9.2 ppm(v) of $SO_4$ and 3200 ppm(v) of $SO_2$ at the precipitator outlet. Selected data sheets follow.

Re: IAD #97-F099-116-02

October 22, 1980

(mg/l)

| Parameter | Sluice Water Blank 9/11/80 41-1,3,5 | Bottom Ash Sluice 9/11/80 41-2,4,6 |
|---|---|---|
| Acidity (as $CaCO_3$) | 23.6 | 67.4 |
| Alkalinity (as $CaCO_3$) | 36.5 | 6.1 |
| BOD | 2 | 7 |
| TSS | 12 | 837 |
| TDS | 1074 | 1066 |
| Specific Conductance (μmhos/cm) | 1400 | 1400 |
| Nitrite (as N) | 0.17 | 0.06 |
| Nitrate (as N) | 2.2 | 1.6 |
| pH | 7.3 | 5.3 |
| Cyanide | ≤0.007 | ≤0.007 |
| COD | ≤7 | 128 |
| Ammonia (as N) | 2.1 | 1.2 |
| TKN (as N) | 8 | 14 |
| TOC | 7 | 11 |

If there are any questions concerning these results, please call.

Bruce A Hale

Bruce A. Hale
Section Supervisor

Robert L Taylor for

Approved: 220.120,
M. L. Jacobs, Ph.D., Mngr.
Instrumental Analysis Division

BAH/ja

**ACUREX Corporation**
**ANALYSIS LABORATORIES**

# DATA REPORTING FORM

CUSTOMER CMEA
DATE 12/30/80
CUSTOMER CONTRACT NO. 307605.42
ACUREX CONTRACT NO. A80-09-023
RESULTS REPORT TO
TELEPHONE
ADDRESS
Conesville 27.1 dscm

| SAMPLE ID (CUSTOMER) | 41-21 | 41-17 | 41-12 | 41-14 | 41-14 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| SAMPLE ID (LAB) | 17-Hg | 12-Hg | 6-Hg | 7-Hg | 7-As, Sb | | | | | |
| PARAMETER | | | | | | | | | | UNITS |
| Type | Filter | XAD | 1st Imp | 2&3 Imp | 2&3 Imp | | | | | |
| Sample Aliquot | 0.72 ug | 4.0 ug | 10 ppb | 9.0 ppb | < 20 | | | | | |
| Blank Aliquot | 0.14 ug | <0.5 ug | 0.7 ppb | NA | NA | | | | | |
| Sample | 0.11 | 19 | 0.62 | 0.53 | < 1 | | | | | ug/dscm |
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ANALYST Cheryl McMillen
REVIEWER Greg Nicoll

Form EED-057 4/80

**COMMERCIAL TESTING & ENGINEERING CO.**
GENERAL OFFICES: 228 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 726-8434
Reply to INSTRUMENTAL ANALYSIS DIVISION, 14335 WEST 44TH AVENUE, GOLDEN, COLORADO 80401, PHONE: 303-278-9521

To: Mr. Jim Steiner
Acurex Corporation
485 Clyde Avenue
Mountain View, CA 94042

Date: March 31, 1981

Analyst: J. Oldham

P. O. No.:

Sample No.: 023-17

IAD No.: 97-F996-116-09

SPARK SOURCE MASS SPECTROGRAPHIC ANALYSIS

CONCENTRATION IN μg/ cm²

Sass Front Half (includes cyclones)

| ELEMENT | CONC. | ELEMENT | CONC. | ELEMENT | CONC. | ELEMENT | CONC. |
|---|---|---|---|---|---|---|---|
| Uranium | 0.04 | Terbium | 0.002 | Ruthenium | | Vanadium | 0.5 |
| Thorium | 0.02 | Gadolinium | 0.003 | Molybdenum | 0.5 | Titanium | MC |
| Bismuth | 0.08 | Europium | 0.002 | Niobium | 0.06 | Scandium | 0.02 |
| Lead | 0.09 | Samarium | 0.02 | Zirconium | 0.09 | Calcium | MC |
| Thallium | | Neodymium | 0.03 | Yttrium | 0.08 | Potassium | >1 |
| Mercury | NR | Praseodymium | 0.01 | Strontium | 0.4 | Chlorine | 0.06 |
| Gold | | Cerium | 0.08 | Rubidium | 0.09 | Sulfur | >0.7 |
| Platinum | | Lanthanum | 0.1 | Bromine | 0.02 | Phosphorus | >4 |
| Iridium | | Barium | * 8 | Selenium | 0.1 | Silicon | >7 |
| Osmium | | Cesium | 0.007 | Arsenic | 2 | Aluminum | >0.1 |
| Rhenium | | Iodine | 0.001 | Germanium | 0.06 | Magnesium | MC |
| Tungsten | 0.006 | Tellurium | | Gallium | 0.09 | Sodium | >0.3 |
| Tantalum | | Antimony | 0.008 | Zinc | 5 | Fluorine | ≈0.2 |
| Hafnium | 0.006 | Tin | 0.01 | Copper | 0.4 | Oxygen | NR |
| Lutetium | <0.001 | Indium | STD | Nickel | 4 | Nitrogen | NR |
| Ytterbium | 0.003 | Cadmium | 0.004 | Cobalt | 0.08 | Carbon | NR |
| Thulium | <0.001 | Silver | 0.1 | Iron | MC | Boron | 0.2 |
| Erbium | 0.002 | Palladium | | Manganese | >1 | Beryllium | 0.002 |
| Holmium | 0.003 | Rhodium | | Chromium | >2 | Lithium | >0.3 |
| Dysprosium | 0.003 | | | | | Hydrogen | NR |

STD — Internal Standard
NR — Not Reported
All elements not detected < 0.001 μg/cm²
MC — Major Component > 10μg/cm²
INT — Interference

Approved: M Y [illegible]

Heterogeneous

**COMMERCIAL TESTING & ENGINEERING CO.**
GENERAL OFFICES: 228 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 726-8434
Reply to INSTRUMENTAL ANALYSIS DIVISION, 14335 WEST 44TH AVENUE, GOLDEN, COLORADO 80401, PHONE: 303-278-9521

To: Mr. Jim Steiner
Acurex Corporation
485 Clyde Avenue
Mountain View, CA 94042

Date: March 31, 1981

Analyst: J. Oldham

P. O. No.:

Sample No.: 023-6

IAD No.: 97-F996-116-09

SPARK SOURCE MASS SPECTROGRAPHIC ANALYSIS
CONCENTRATION IN µg/ml

Sass - 1st Impinger

| ELEMENT | CONC. | ELEMENT | CONC. | ELEMENT | CONC. | ELEMENT | CONC. |
|---|---|---|---|---|---|---|---|
| Uranium | <0.002 | Terbium | | Ruthenium | | Vanadium | 0.03 |
| Thorium | <0.003 | Gadolinium | | Molybdenum | 0.4 | Titanium | 0.4 |
| Bismuth | 0.3 | Europium | 0.002 | Niobium | 0.07 | Scandium | <0.001 |
| Lead | 0.05 | Samarium | 0.007 | Zirconium | 0.02 | Calcium | 2 |
| Thallium | | Neodymium | 0.002 | Yttrium | <0.001 | Potassium | 1 |
| Mercury | NR | Praseodymium | 0.004 | Strontium | 0.05 | Chlorine | 0.02 |
| Gold | | Cerium | 0.002 | Rubidium | <0.001 | Sulfur | MC |
| Platinum | | Lanthanum | 0.04 | Bromine | ≤0.003 | Phosphorus | 0.1 |
| Iridium | | Barium | MC | Selenium | 0.02 | Silicon | 1 |
| Osmium | | Cesium | <0.001 | Arsenic | 0.003 | Aluminum | 0.008 |
| Rhenium | | Iodine | <0.001 | Germanium | <0.001 | Magnesium | 0.09 |
| Tungsten | 0.01 | Tellurium | | Gallium | 0.005 | Sodium | MC |
| Tantalum | 0.003 | Antimony | <0.001 | Zinc | 2 | Fluorine | ≈0.5 |
| Hafnium | | Tin | 0.01 | Copper | 0.05 | Oxygen | NR |
| Lutetium | | Indium | STD | Nickel | MC | Nitrogen | NR |
| Ytterbium | | Cadmium | 0.002 | Cobalt | 0.6 | Carbon | NR |
| Thulium | | Silver | 0.006 | Iron | MC | Boron | 0.008 |
| Erbium | | Palladium | | Manganese | MC | Beryllium | |
| Holmium | | Rhodium | | Chromium | MC | Lithium | 0.01 |
| Dysprosium | | | | | | Hydrogen | NR |

STD — Internal Standard
NR — Not Reported
All elements not detected < 0.001 µg/ml
MC — Major Component > 10 µg/ml
INT — Interference

Approved: M Jacobs

**COMMERCIAL TESTING & ENGINEERING CO.**
GENERAL OFFICES: 228 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 726-8434
Reply to INSTRUMENTAL ANALYSIS DIVISION, 1335 WEST 44TH AVENUE, GOLDEN, COLORADO 80401, PHONE: 303-278-9521

To: Mr. Jim Steiner
Acurex Corporation
485 Clyde Avenue
Mountain View, CA 94042

Date: March 31, 1981

Analyst: J. Oldham

P. O. No.:

Sample No.: 023-12

IAD No.: 97-F996-116-09

## SPARK SOURCE MASS SPECTROGRAPHIC ANALYSIS
## CONCENTRATION IN PPM WEIGHT

Sass - XAD-2

| ELEMENT | CONC. | ELEMENT | CONC. | ELEMENT | CONC. | ELEMENT | CONC. |
|---|---|---|---|---|---|---|---|
| Uranium | <0.5 | Terbium | | Ruthenium | | Vanadium | 0.1 |
| Thorium | <0.6 | Gadolinium | | Molybdenum | 7 | Titanium | 3 |
| Bismuth | 0.2 | Europium | | Niobium | <0.1 | Scandium | <0.1 |
| Lead | 0.5 | Samarium | | Zirconium | 4 | Calcium | 92 |
| Thallium | | Neodymium | | Yttrium | <0.1 | Potassium | 18 |
| Mercury | NR | Praseodymium | | Strontium | 0.3 | Chlorine | 4 |
| Gold | | Cerium | 0.2 | Rubidium | <0.1 | Sulfur | 50 |
| Platinum | **0.7 | Lanthanum | 0.3 | Bromine | *1 | Phosphorus | 3 |
| Iridium | | Barium | 3 | Selenium | 0.4 | Silicon | 56 |
| Osmium | | Cesium | | Arsenic | <0.1 | Aluminum | 1 |
| Rhenium | | Iodine | <0.1 | Germanium | | Magnesium | 3 |
| Tungsten | | Tellurium | | Gallium | 1 | Sodium | 8 |
| Tantalum | | Antimony | | Zinc | 11 | Fluorine | *≈1 |
| Hafnium | | Tin | | Copper | 2 | Oxygen | NR |
| Lutetium | | Indium | STD | Nickel | 27 | Nitrogen | NR |
| Ytterbium | | Cadmium | | Cobalt | *0.2 | Carbon | NR |
| Thulium | | Silver | <0.1 | Iron | 39 | Boron | 0.6 |
| Erbium | | Palladium | | Manganese | 0.8 | Beryllium | |
| Holmium | | Rhodium | | Chromium | *19 | Lithium | |
| Dysprosium | | | | | | Hydrogen | NR |

* Heterogeneous
** Probable contamination from Parr oxygen bomb ignition wire.

STD — Internal Standard
NR — Not Reported
All elements not detected <0.1 ppm
MC — Major Component
INT — Interference

Approved: M Jacobs

**COMMERCIAL TESTING & ENGINEERING CO.**
GENERAL OFFICES: 228 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 726-8434
Reply to INSTRUMENTAL ANALYSIS DIVISION, 14335 WEST 44TH AVENUE, GOLDEN, COLORADO 80401, PHONE: 303-278-9521

To: Mr. Jim Steiner
Acurex Corporation
485 Clyde Avenue
Mountain View, CA 94042

Date: March 31, 1981

Analyst: J. Oldham

P. O. No.:

Sample No.: 023-20

IAD No.: 97-F996-116-09

## SPARK SOURCE MASS SPECTROGRAPHIC ANALYSIS

CONCENTRATION IN μg/ml

1st Impinger Blank

| ELEMENT | CONC. | ELEMENT | CONC. | ELEMENT | CONC. | ELEMENT | CONC. |
|---|---|---|---|---|---|---|---|
| Uranium | <0.002 | Terbium | | Ruthenium | | Vanadium | <0.001 |
| Thorium | <0.002 | Gadolinium | | Molybdenum | *0.008 | Titanium | 0.03 |
| Bismuth | | Europium | | Niobium | <0.001 | Scandium | <0.001 |
| Lead | 0.002 | Samarium | | Zirconium | <0.001 | Calcium | 0.7 |
| Thallium | | Neodymium | | Yttrium | <0.001 | Potassium | 0.2 |
| Mercury | NR | Praseodymium | | Strontium | 0.004 | Chlorine | 0.06 |
| Gold | | Cerium | | Rubidium | <0.001 | Sulfur | 0.8 |
| Platinum | | Lanthanum | | Bromine | ≤0.005 | Phosphorus | 0.2 |
| Iridium | | Barium | 0.02 | Selenium | <0.001 | Silicon | 0.2 |
| Osmium | | Cesium | | Arsenic | <0.001 | Aluminum | 0.01 |
| Rhenium | | Iodine | | Germanium | | Magnesium | 0.06 |
| Tungsten | | Tellurium | | Gallium | <0.001 | Sodium | 0.7 |
| Tantalum | **<0.001 | Antimony | | Zinc | 0.04 | Fluorine | =0.001 |
| Hafnium | | Tin | 0.005 | Copper | 0.004 | Oxygen | NR |
| Lutetium | | Indium | STD | Nickel | 0.01 | Nitrogen | NR |
| Ytterbium | | Cadmium | <0.001 | Cobalt | <0.001 | Carbon | NR |
| Thulium | | Silver | | Iron | 0.07 | Boron | <0.001 |
| Erbium | | Palladium | | Manganese | <0.001 | Beryllium | |
| Holmium | | Rhodium | | Chromium | 0.001 | Lithium | |
| Dysprosium | | | | | | Hydrogen | NR |

* Heterogeneous
** Probable contamination

STD — Internal Standard
NR — Not Reported
All elements not detected < 0.001 μg/ml
MC — Major Component > 10 μg/ml
INT — Interference

Approved:

**COMMERCIAL TESTING & ENGINEERING CO.**
GENERAL OFFICES: 228 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 726-8434
Reply to INSTRUMENTAL ANALYSIS DIVISION, 14335 WEST 44TH AVENUE, GOLDEN, COLORADO 80401, PHONE 303-278-9521

To: Mr. Jim Steiner
Acurex Corporation
485 Clyde Avenue
Mountain View, CA 94042

Date. March 31, 1981

Analyst: J. Oldham

P. O. No.:

Sample No.: 023-4

IAD No.: 97-F996-116-09

SPARK SOURCE MASS SPECTROGRAPHIC ANALYSIS

CONCENTRATION IN $\mu g/cm^2$

Sass - Filter Blank

| ELEMENT | CONC. | ELEMENT | CONC. | ELEMENT | CONC. | ELEMENT | CONC. |
|---|---|---|---|---|---|---|---|
| Uranium | <0.001 | Terbium | | Ruthenium | | Vanadium | 0.003 |
| Thorium | <0.001 | Gadolinium | | Molybdenum | 0.002 | Titanium | 0.2 |
| Bismuth | | Europium | | Niobium | <0.001 | Scandium | <0.001 |
| Lead | 0.001 | Samarium | | Zirconium | 0.009 | Calcium | 7 |
| Thallium | | Neodymium | <0.001 | Yttrium | <0.001 | Potassium | 0.04 |
| Mercury | NR | Praseodymium | <0.001 | Strontium | 0.01 | Chlorine | 0.09 |
| Gold | | Cerium | 0.002 | Rubidium | <0.001 | Sulfur | 0.02 |
| Platinum | | Lanthanum | 0.004 | Bromine | 0.003 | Phosphorus | 0.01 |
| Iridium | | Barium | 0.02 | Selenium | <0.001 | Silicon | MC |
| Osmium | | Cesium | | Arsenic | <0.001 | Aluminum | >0.2 |
| Rhenium | | Iodine | <0.001 | Germanium | <0.001 | Magnesium | 0.7 |
| Tungsten | | Tellurium | | Gallium | 0.001 | Sodium | 0.4 |
| Tantalum | | Antimony | | Zinc | 0.01 | Fluorine | ≈0.05 |
| Hafnium | | Tin | | Copper | 0.005 | Oxygen | NR |
| Lutetium | | Indium | STD | Nickel | <0.001 | Nitrogen | NR |
| Ytterbium | | Cadmium | <0.001 | Cobalt | <0.001 | Carbon | NR |
| Thulium | | Silver | <0.001 | Iron | 0.05 | Boron | 0.1 |
| Erbium | | Palladium | | Manganese | <0.001 | Beryllium | |
| Holmium | | Rhodium | | Chromium | 0.004 | Lithium | 0.002 |
| Dysprosium | | | | | | Hydrogen | NR |

STD — Internal Standard
NR — Not Reported
All elements not detected <0.001 $\mu g/cm^2$
MC — Major Component > 10$\mu g/cm^2$
INT — Interference

Approved: M Jacobs

**COMMERCIAL TESTING & ENGINEERING CO.**
GENERAL OFFICES: 228 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 723-8434
Reply to INSTRUMENTAL ANALYSIS DIVISION, 14335 WEST 44TH AVENUE, GOLDEN, COLORADO 80401, PHONE: 303-278-9521

To: Mr. Jim Steiner
Acurex Corporation
485 Clyde Avenue
Mountain View, CA 94042

Date: March 31, 1981

Analyst: J. Oldham

P. O. No.:

Sample No.: 023

XAD-2 Blank

IAD No.: 97-F996-116-09

## SPARK SOURCE MASS SPECTROGRAPHIC ANALYSIS
## CONCENTRATION IN PPM WEIGHT

| ELEMENT | CONC. | ELEMENT | CONC. | ELEMENT | CONC. | ELEMENT | CONC. |
|---|---|---|---|---|---|---|---|
| Uranium | <1 | Terbium | | Ruthenium | | Vanadium | <0.1 |
| Thorium | <1 | Gadolinium | | Molybdenum | 5 | Titanium | 5 |
| Bismuth | | Europium | | Niobium | | Scandium | <0.1 |
| Lead | | Samarium | | Zirconium | 4 | Calcium | 92 |
| Thallium | | Neodymium | | Yttrium | | Potassium | 25 |
| Mercury | NR | Praseodymium | | Strontium | 0.1 | Chlorine | 7 |
| Gold | | Cerium | 0.4 | Rubidium | | Sulfur | 5 |
| Platinum | *0.8 | Lanthanum | 0.4 | Bromine | | Phosphorus | 3 |
| Iridium | | Barium | 4 | Selenium | | Silicon | 140 |
| Osmium | | Cesium | | Arsenic | | Aluminum | 3 |
| Rhenium | | Iodine | | Germanium | | Magnesium | 19 |
| Tungsten | | Tellurium | | Gallium | ≤0.1 | Sodium | 4 |
| Tantalum | | Antimony | | Zinc | 27 | Fluorine | ≈1 |
| Hafnium | | Tin | | Copper | 9 | Oxygen | NR |
| Lutetium | | Indium | STD | Nickel | 10 | Nitrogen | NR |
| Ytterbium | | Cadmium | | Cobalt | ≤0.1 | Carbon | NR |
| Thulium | | Silver | | Iron | 4 | Boron | 2 |
| Erbium | | Palladium | | Manganese | 0.4 | Beryllium | |
| Holmium | | Rhodium | | Chromium | 1 | Lithium | 0.2 |
| Dysprosium | | | | | | Hydrogen | NR |

* Probable contamination from Parr oxygen bomb ignition wire.

STD — Internal Standard
NR — Not Reported
All elements not detected <0.2 ppm
MC — Major Component
INT — Interference

Approved:

ACUREX Corporation
ANALYSIS LABORATORIES

# DATA REPORTING FORM

CUSTOMER CMEA DATE 12/1/80
CUSTOMER CONTRACT NO. 307605.42 ACUREX CONTRACT NO. A80-09-023
RESULTS REPORT TO TELEPHONE
ADDRESS
Conesville

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| SAMPLE ID (CUSTOMER) | 41-18 | 41-19 | 41-20 | 41-21 | | | | | | |
| SAMPLE ID (LAB) | 2 | 11 | 10 | 17 | | | | | | |
| PARAMETER | | | | | | | | | | UNITS |
| Type | Filter | 10µ | 3µ | wash+1µ | | | | | | |
| ASH | 0.0758 | 0.1844 | 0.1365 | 0.1056 | | | | | | gram |
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ANALYST Greg Nicoll
REVIEWER

Form EED 062 4-80

**ACUREX Corporation**
**ANALYSIS LABORATORIES**

# DATA REPORTING FORM

CUSTOMER CNEA
DATE 12/1/80
CUSTOMER CONTRACT NO. 307605.42
ACUREX CONTRACT NO. A80-09-023
RESULTS REPORT TO
TELEPHONE
ADDRESS
Conesville 27.1 dscm

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| SAMPLE ID (CUSTOMER) | 41-16 | 41-17 | 41-18 | | | 41-9 | | | | |
| SAMPLE ID (LAB) | 14 | 12 | 17 | XAD Blk | $CH_2Cl_2$ Blk | 3 | | | | |
| PARAMETER | | | | | | | | | | UNITS |
| Type | OMC | XAD | FH | | | Filter Blk | | | | |
| TCO | 0.21 | 43 | | 0.5 | 0.004 | | | | | mg |
| TCO, corrected | 0.21 | 42 | | | | | | | | mg |
| GRAV | <2 | 2600 | 4 | <2 | <2 | <2 | | | | mg |
| GRAV, corrected | <2 | 2600 | 4 | | | | | | | mg |
| TCO & GRAV | <2 | 2600 | 4 | | | | | | | mg |
| TCO & GRAV | <0.07 | 96 | 0.1 | | | | | | | mg/dscm |
| | | | | | | | | | | |
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ANALYST Greg Nicoll
REVIEWER

Form EED-057 4/80

**IR REPORT**

**SAMPLE:** A80-09-023-3 Filter Blank

| Wave Number (cm$^{-1}$) | Intensity | Assignment | Comments |
|---|---|---|---|
| 2920-2380 | S | C-H (Alkane); O-H (COOH) | Weak |

Greg Nicoll

**IR REPORT**

**SAMPLE:** A80-09-023-17 Front Half

| Wave Number (cm$^{-1}$) | Intensity | Assignment | Comments |
|---|---|---|---|
| 2915 | S | C-H Alkane | |
| 2840 | S | C-H Alkane | |
| 2780-2365 | W | O-H (COOH) | |
| 1700 | W | C-O (COOH) | |
| 1445 | W | C-H Alkane | |
| 1260 | S | C-O (COOH) | |
| 1015 | M | C-O | |
| 790 | S | C-H rock | |

Greg Nicoll

**IR REPORT**

**SAMPLE:** A80-09-023 XAD BLANK

| Wave Number ($cm^{-1}$) | Intensity | Assignment | Comments |
|---|---|---|---|
| 2920 | S | C-H Alkane | Weak |
| 2850 | S | C-H Alkane | Weak |
| 2780-2380 | W | O-H (COOH) | Weak |

Greg Nicoll

**IR REPORT**

**SAMPLE:** A80-09-023-12 XAD

| Wave Number (cm$^{-1}$) | Intensity | Assignment | Comments |
|---|---|---|---|
| 3700-2950 | S | O-H (COOH) | |
| 2900 | S | C-H alkane | |
| 2650-2450 | W | O-H (COOH) | |
| 1610 | W | C=C Aromatic | |
| 1450 | W | C-H Alkane | |
| 1200 | S | C-O | |
| 1060 | W | C-O | |
| 995 | M | C-C Alkane | |
| 875 | W | C-H Aromatic | |
| 775 | M | C-H rock | |

Greg Nicoll

**IR REPORT**

**SAMPLE:** A80-09-023 Methylene Chloride Blank

| Wave Number (cm$^{-1}$) | Intensity | Assignment | Comments |
|---|---|---|---|
| 2920-2380 | S | C-H Alkane; O-H (COOH) | Weak |
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Greg Nicoll

**IR REPORT**

**SAMPLE:** A80-09-023-14 OMC

| Wave Number (cm$^{-1}$) | Intensity | Assignment | Comments |
|---|---|---|---|
| | | No Peaks | |
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Greg Nicoll

**ACUREX Corporation**
**ANALYSIS LABORATORIES**

# DATA REPORTING FORM

CUSTOMER CMEA DATE 12/15/80
CUSTOMER CONTRACT NO. 307605.42 ACUREX CONTRACT NO. A80-09-023
RESULTS REPORT TO TELEPHONE
ADDRESS
Conesville

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SAMPLE ID (CUSTOMER) | 41-21 | 41-17 | 41-16 | 41-27 | 41-8 | | | | | | |
| SAMPLE ID (LAB) | 17 | 12 | 14 | 5 | 24 | | | | | | |
| PARAMETER | | | | | | | | | | | UNITS |
| Type | FH | XAD | OMC | Fly Ash | Sluice | | | | | | |
| Amount taken | 60% | 92% | 100% | 50g | 2 1 | | | | | | |
| Final volume | 1 | 65 | 1 | 1 | 1 | | | | | | ml |
| Phenol | clean | 16 | 80 | clean | clean | | | | | | ng/ul |
| 2,4-Dinitrophenol | | 10 | 4 | | | | | | | | ng/ul |
| Dimethyl phthalate | | 140 | | | | | | | | | ng/ul |
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ANALYST B.D, S.K. and G.C.
REVIEWER Greg Niell

Form EED-037 4/80

ACUREX Corporation
ANALYSIS LABORATORIES

# DATA REPORTING FORM

CUSTOMER CHEA
DATE 12/15/80
CUSTOMER CONTRACT NO. 307605.42
ACUREX CONTRACT NO. A80-09-023
RESULTS REPORT TO
TELEPHONE
ADDRESS
Conesville 27.1 dscm

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| SAMPLE ID (CUSTOMER) | 41-21 | 41-17 | 41-16 | 41-27 | 41-8 | | | | | |
| SAMPLE ID (LAB) | 17 | 12 | 14 | 5 | 24 | | | | | |
| PARAMETER | | | | | | | | | | UNITS |
| Type | FH | XAD | OMC | Fly Ash | Sluice | | | | | |
| Phenol | | 43 | 3.0 | | | | | | | ug/dscm |
| 2,4-Dinitrophenol | | 28 | 0.1 | | | | | | | ug/dscm |
| Dimethyl phthalate | | 370 | | | | | | | | ug/dscm |
| All others | <0.06 | <3 | <0.04 | | | | | | | ug/dscm |
| All others | | | | <0.02 | | | | | | ug/g |
| All others | | | | | <0.5 | | | | | ug/l |
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ANALYST B.D., S.K. and G.C.
REVIEWER Greg Nicoll

Form [illegible]

## APPENDIX J

### Exxon Summary and Analysis of Research Triangle Institute (RTI) and Battelle Bio-Assay Reports

The following pages summarize the biological testing reports by Battelle Columbus Laboratories (BCL) and Research Triangle Institute (RTI). This summary was written by Mr. J. S. Leary, a biological toxicologist, and consultant to ER&E.

## LEVEL 1 ENVIRONMENTAL ASSESSMENT, BIOLOGICAL TESTS FOR PILOT STUDIES CONESVILLE BOILER

### Summary

The objective of the biological testing portion of this project was to define the toxicity of effluents and byproducts resulting from the combustion of coal in a power plant boiler. The results of this biological study are intended to complement the chemical and physical data gathered in the Level 1 Environmental Assessment program and to serve as a guide in the planning of subsequent levels of study. The results indicate that the coal, electrostatic precipitator ash (ESP) and sluice water are not mutagenic. The Rat Alveolar Machrophage (RAM) Assays were also negative. The Chinese Hamster Ovary Cell Assay yielded toxic responses with coal leachates and sluice water. ESP ash was not subjected to this assay. Moderate to high toxicity was also recorded for some of the aquatic assays. Sluice water caused no toxicity to any of the aquatic species studied, but was stimulatory to the growth of algae.

### Identity of Samples:

TABLE GJ-1

SAMPLE IDENTITIES

| SAMPLE TYPE | CONESVILLE<br>RTI<br>EXXON CODES | <br>BATTELLE |
|---|---|---|
| Electrostatic Precipitator Ash<br>Sample Size | MRD-80-61<br>2 Kg | MRD-80-58<br>Ca 60 Kg |
| Sluice Water<br>Sample Size | MRD-80-60<br>2 Liters | MRD-80-57<br>25 Gal |
| Pulverized Coal<br>Sample Size | MRD-80-62<br>2 Kg | MRD-80-59<br>Ca 60 Kg |

### Sample preparation for assays was as follows:

### Electrostatic Precipitator Ash

| Study Type | Preparation |
|---|---|
| Ames Assay | ESP ash added directly to Dimethylsulfoxide at 1000, 250, 50, 5 and 1 micrograms/plate. |
| Rat Alveolar Macrophage | ESP ash added directly to cell medium at 1000, 500, 100, 50 and 10 micrograms/mL. |

| | |
|---|---|
| Rat Acute Oral Study | ESP ash added directly to distilled water at a rate of 1 g/mL. |
| Aquatic Studies<br>o Fresh Water Algal Assay<br>o Static Fish Assay<br>o Daphnia Assay | 700 grams of ESP ash/gal of distilled water agitated for 48 hours - supernatant decanted and filtered through 0.45 μm milipore membrane filter. |

### Sluice Water

Sterilized by millipore filtration.

| Study Type | Preparation |
|---|---|
| Ames Assay | 100, 10, 5, 1 and 0.1 microliters/plate. |
| Chinese Hamster Ovarian Assay | 71, 36, 18, 3 and 0.3 microliters/mL of cell medium. |
| Rat Acute Oral Study | 10 mL/Kg of body weight. |
| Aquatic Studies | Used as supplied. |

### Pulverized Coal

| Study Type | Preparation |
|---|---|
| Ames Assay | Coal ground and screened through 212 μm size membrane and added directly to Dimethylsulfoxide at 1000, 250, 50, 5, and 1 microgram/plate. |
| Rat Alveolar Macrophage | Coal ground and screened through 212 μm size mesh and added to cell medium at a concentrations of 1000, 500, 100, 50 and 10 micrograms/mL. |
| Rat Acute Oral Study | 212 μm size pulverized coal added to distilled water at a level of 1 g/mL - 10 mL/Kg of body weight. |
| Aquatic Studies<br>o Fresh Water Algal Assay<br>o Static Fish Assay<br>o Daphnia Assay | 700 grams of ESP ash/gal of distilled water agitated for 48 hours - supernatant decanted and filtered through 0.45 μm Millipore membrane filter. |

### Coal Leachate

Pulverized coal ground in Waring Blender and leached in distilled water at 20°C for 16 hours and sterilized by millipore filtration.

| Study Type | Preparation |
|---|---|
| Ames Assay | Above leachate added at 100, 10, 5, 1 and 0.1 microliters/plate. |
| Chinese Hamster Ovarian Assay | Above leachate added to cell media at 71, 36, 18, 3 and 0.3 microliters/mL DMSO. |
| Rat Acute Oral Study | Above leachate administered as is at 10 mL/Kg of body weight. |

Coal Extract

| | |
|---|---|
| (Conesville Boiler Only) | 100 grams of pulverized coal extracted with Soxhlet using 600 mL methylene chloride. Evaporated to dryness weighted and reconstituted in Dimethylsulfoxide. |

| Study Type | Preparation |
|---|---|
| Ames Assay | Added at level of 1000, 250, 50, 5 and 1 micrograms/plate. |

NOTE: Special effort was made in a supplemental study of coal leachate and sluice water concentrates due to lack of cytotoxicity in the Ames Study.

## Methodology

There were some modifications of the Ames Assay, but these changes may not have affected the test performance except that the positive controls appear to be lower in response than might have been expected. Thus marginal responses in the test samples could have gone unnoticed.

In the basic Level 1 biological testing program, it is recognized that useful information could also have been obtained through the study of sub samples from the Source Assessment Sampling System (SASS). However, in these present studies the total sample from the SASS was quite small and could be utilized only with regard to the physical and chemical assays.

## Results

A brief summary of the toxicity rankings can be found in Table GJ-2.

The Ames Assay (Tables GJ-3 through GJ-8) was essentially negative for all samples tested and except for a cytotoxic response in the Soxhlet extracted pulverized coal assay, no toxicity was recorded. Concentrated coal leachate, assayed at doses from 1 µL/plate up to the toxic dose of 50 µL/plate, was not mutagenic for either the frameshift strains (TA 1537, TA 1538 and TA 98)

## TABLE GJ-2

## TOXICOLOGY RANKINGS

### Conesville Samples

| Test | Hopper Ash | Sluice Water | Pul. Coal |
|---|---|---|---|
| Ames | UD | UD | UD |
| RAM | UD | NT | UD |
| CHO | NT | L | M |
| Rat Oral In Vivo | UD | UD | UD |
| Fat Head Minnow | M | UD | M |
| Daphnia Magna | M | UD | M |
| Algae | H | UD | M |

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H = High Toxicity (Activity)

M = Moderate Toxicity (Activity)

L = Low Toxicity (Activity)

UD = Undetected

NT = Not Tested

See Tables GJ-12 through GJ-16 for suggested ranking of biological activity.

### Table GJ-3. Toxicity Results - Boiler 1 Samples (Conesville)

| | | Survivor Ratio[a] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | TA 98 | | TA 1538 | | TA 100 | | TA 1535 | | TA 1537 | |
| Sample | Amount μg/plate | -S9 | +S9 | -S9 | +S9 | -S9 | +S9 | -S9 | +S9 | -S9 | +S9 |
| Coal-Soxhlet Extraction | 1000 | 0.03 | 1.2 | 0.0 | 0.7 | 0.01 | 0.4 | 0.03 | 0.09 | 0.0 | 0.4 |
| | 250 | 0.07 | 1.2 | 0.02 | 0.9 | 0.02 | 1.3 | 0.10 | 0.9 | 0.02 | 0.9 |
| | 50 | 0.4 | 1.1 | 0.4 | 0.9 | 0.4 | 1.2 | 0.4 | 1.0 | 0.2 | 1.0 |
| | 5 | 0.9 | 1.2 | 0.9 | 0.9 | 1.2 | 1.2 | 1.0 | 0.9 | 0.9 | 0.9 |
| | 1 | 1.0 | 1.0 | 0.8 | 1.0 | 1.0 | 1.2 | 1.0 | 1.0 | 0.9 | 0.9 |
| ESP Ash | 1000 | 0.9 | 1.3 | 1.0 | 1.0 | 1.3 | 1.2 | 1.0 | 1.0 | 0.9 | 0.9 |
| | 250 | 0.9 | 1.2 | 1.0 | 1.0 | 1.2 | 1.2 | 1.0 | 1.0 | 0.9 | 0.9 |
| | 50 | 0.9 | 1.0 | 1.0 | 0.8 | 1.2 | 1.2 | 1.1 | 1.0 | 0.9 | 0.9 |
| | 5 | 0.8 | 1.2 | 1.0 | 1.0 | 1.1 | 1.2 | 1.0 | 1.1 | 0.9 | 1.0 |
| | 1 | 0.9 | 1.1 | 1.0 | 1.0 | 1.1 | 1.1 | 1.1 | 1.0 | 0.9 | 0.8 |
| Pulverized Coal | 1000 | 1.0 | 1.2 | 0.9 | 0.9 | 1.1 | 1.0 | 0.6 | 1.0 | 1.1 | 1.0 |
| | 250 | 1.0 | 1.3 | 1.1 | 1.0 | 1.1 | 1.1 | 0.8 | 0.9 | 0.9 | 1.0 |
| | 50 | 1.1 | 1.1 | 0.9 | 0.9 | 1.1 | 1.2 | 1.0 | 1.1 | 1.0 | 1.0 |
| | 5 | 1.1 | 1.1 | 1.0 | 0.9 | 1.2 | 1.0 | 1.0 | 1.1 | 1.1 | 1.0 |
| | 1 | 1.1 | 1.2 | 1.1 | 0.9 | 1.2 | 1.1 | 0.9 | 1.0 | 1.2 | 1.1 |
| | Amount μL/plate | | | | | | | | | | |
| Sluice Water | 100 | 1.0 | 1.2 | 1.1 | 0.9 | 0.9 | 0.9 | 1.0 | 1.0 | 0.8 | 1.0 |
| | 10 | 0.9 | 1.2 | 1.2 | 0.9 | 0.9 | 0.9 | 0.9 | 1.0 | 0.9 | 1.0 |
| | 5 | 0.9 | 1.1 | 1.1 | 0.9 | 1.1 | 1.0 | 0.8 | 1.1 | 0.9 | 1.0 |
| | 1 | 1.0 | 1.0 | 1.1 | - | 1.0 | 0.9 | 0.8 | 1.1 | 1.1 | 1.0 |
| | 0.1 | 1.2 | 1.0 | 1.2 | - | 1.0 | 1.0 | 1.0 | 1.2 | 1.0 | 1.0 |
| Coal Leachate | 100 | 1.1 | 1.0 | 1.0 | 0.8 | 1.1 | 1.4 | 0.8 | 0.8 | 0.7 | 1.1 |
| | 10 | 1.1 | 0.9 | 1.1 | 0.6 | 1.2 | 1.3 | 1.1 | 0.9 | 1.0 | 1.1 |
| | 5 | 1.2 | 1.1 | 1.0 | 0.9 | 1.2 | 1.3 | 1.1 | 0.9 | 1.0 | 1.0 |
| | 1 | 1.2 | 1.1 | 1.1 | 1.0 | 1.1 | 1.3 | 1.0 | 0.8 | 1.0 | 1.0 |
| | 0.1 | 1.2 | - | 1.1 | 0.6 | 1.2 | 1.3 | 1.0 | 1.0 | 0.9 | 1.0 |

[a] Colonies in sample plate/colonies in solvent control.

## AMES ASSAYS

Table GJ-4. Mutagenicity Results - Average Number of Revertants - Boiler 1 (Conesville)

| | | Average Number of Revertants[a] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | TA 98 | | TA 1538 | | TA 100 | | TA 1535 | | TA 1537 | |
| Sample | Amount μg/plate | -S9 | +S9 | -S9 | +S9 | -S9 | +S9 | -S9 | +S9 | -S9 | +S9 |
| Coal-Soxhlet Extraction | 1000 | 26 | 71 | 4 | 7 | 110 | 179 | 20 | 45 | 3 | 5 |
| | 250 | 25 | 70 | 11 | 31 | 120 | 197 | 19 | 33 | 3 | 22 |
| | 50 | 30 | 85 | 7 | 25 | 141 | 177 | 29 | 37 | 5 | 20 |
| | 5 | 29 | 51 | 8 | 8 | 134 | 174 | 30 | 39 | 9 | 15 |
| | 1 | 31 | 48 | 9 | 17 | 133 | 169 | 36 | 43 | 8 | 13 |
| ESP Ash | 1000 | 33 | 50 | 12 | 17 | 96 | 143 | 3 | 13 | 7 | 27 |
| | 250 | 29 | 49 | 4 | 24 | 114 | 125 | 8 | 10 | 7 | 21 |
| | 50 | 28 | 55 | 8 | 11 | 134 | 143 | 11 | 15 | 9 | 21 |
| | 5 | 32 | 48 | 1 | 19 | 126 | 135 | 8 | 18 | 1 | 9 |
| | 1 | 33 | 41 | - | 17 | 128 | 125 | 6 | 10 | 5 | 19 |
| Pulverized Coal | 1000 | 22 | 39 | 11 | 27 | 146 | 233 | 7 | 19 | 8 | 13 |
| | 250 | 21 | 26 | 9 | 15 | 166 | 201 | 3 | 15 | 8 | 16 |
| | 50 | 19 | 30 | 8 | 22 | 138 | 197 | 1 | 12 | 6 | 10 |
| | 5 | 19 | 32 | 13 | 23 | 142 | 173 | 2 | 11 | 6 | 14 |
| | 1 | 21 | 30 | 13 | 35 | 134 | 165 | 1 | 14 | 6 | 10 |
| | Amount μL/plate | | | | | | | | | | |
| Sluice Water | 100 | 39 | 56 | 1 | 21 | 104 | 120 | 35 | 36 | 5 | 13 |
| | 10 | 48 | 73 | 10 | 18 | 104 | 141 | 35 | 31 | 2 | 21 |
| | 5 | 41 | 64 | 9 | 22 | 98 | 114 | 46 | 38 | 3 | 18 |
| | 1 | 47 | 66 | - | 16 | 109 | 109 | 43 | 42 | 6 | 25 |
| | 0.1 | 42 | 80 | 4 | 11 | 114 | 111 | 29 | 29 | 3 | 14 |
| Coal Leachate | 100 | 35 | 31 | 14 | 30 | 151 | 212 | 8 | 19 | 8 | 14 |
| | 10 | 29 | 36 | 16 | 26 | 176 | 199 | - | 16 | 11 | 11 |
| | 5 | 18 | 30 | 13 | 27 | 166 | 218 | 1 | 13 | 11 | 15 |
| | 1 | 23 | 37 | 8 | 40 | 143 | 210 | 6 | 8 | 9 | 12 |
| | 0.1 | 24 | 32 | 8 | 21 | 153 | 189 | 10 | 9 | 7 | 14 |

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[a] Average number of revertants from 3 replicate plates per dose.

Note: All 5 samples were not assayed on the same day.

## AMES ASSAYS

Table GJ-5. Positive Controls - Mutagenic Ratio

| Sample | Amount µg/plate | Mutagenic Ratio[a] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | TA 98 | | TA 1538 | | TA 100 | | TA 1535 | | TA 1537 | |
| | | -S9 | +S9 | -S9 | +S9 | -S9 | +S9 | -S9 | +S9 | -S9 | +S9 |
| 2AN | 100 | 2 | 28 | 1 | 15 | 1 | 8 | 1 | 3 | 1 | 25 |
| | 10 | | 22 | | 38 | | 9 | | 4 | | 31 |
| | 1 | | 5 | | 10 | | 3 | | 2 | | 3 |
| 2NF | 100 | 20 | | 19 | | | | | | | |
| | 10 | 11 | | 32 | | | | | | | |
| | 1 | 3 | | 6 | | | | | | | |
| SA | 100 | | | | | 5 | | 18 | | | |
| | 10 | | | | | 3 | | 13 | | | |
| | 1 | | | | | 1 | | 6 | | | |
| QHCL | 250 | | | | | | | | | 102 | |
| | 25 | | | | | | | | | .9 | |
| | 2.5 | | | | | | | | | .8 | |

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[a] Revertants in test plate/revertants in solvent control.

Key

2AN: 2-aminoanthracene
2NF: 2-nitrofluorene
SA: Sodium azide
QHCL: Quinacrine hydrochloride

## AMES ASSAYS

Table GJ-6. Positive Controls - Number of Revertants

| Sample | Amount µg/plate | Average Number of Revertants[a] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | TA 98 | | TA 1538. | | TA 100 | | TA 1535 | | TA 1537 | |
| | | -S9 | +S9 | -S9 | +S9 | -S9 | +S9 | -S9 | +S9 | -S9 | +S9 |
| 2AN | 100 | 49 | 1209 | 25 | 369 | 121 | 1253 | 73 | 97 | 9 | 222 |
| | 10 | | 940 | | 963 | | 1492 | | 111 | | 277 |
| | 1 | | 205 | | 263 | | 458 | | 72 | | 26 |
| DMSO | 100 | 28 | 43 | 18 | 25 | 147 | 158 | 65 | 32 | 7 | 9 |
| 2NF | 100 | 546 | | 349 | | | | | | | |
| | 10 | 321 | | 570 | | | | | | | |
| | 1 | 95 | | 105 | | | | | | | |
| DMSO | 100 | 28 | | 18 | | | | | | | |
| SA | 100 | | | | | 756 | | 1192 | | | |
| | 10 | | | | | 451 | | 841 | | | |
| | 1 | | | | | 208 | | 416 | | | |
| $H_2O$ | 100 | | | | | 141 | | 65 | | | |
| QHCL | 250 | | | | | | | | | 712 | |
| | 25 | | | | | | | | | 6 | |
| | 2.5 | | | | | | | | | 6 | |
| DMSO | | | | | | | | | | 7 | |

[a] Average revertants per plate from 3 replicate plates per dose.

Key

2AN: 2-aminoanthracene
2NF: 2-nitrofluorene
SA: Sodium azide
QHCL: Quinacrine hydrochloride
DMSO: Dimethylsulfoxide

Table GJ-7. Solvent Controls for Samples - Average Number of Revertants

| Sample | Amount µL/plate | Average Number of Revertants[a] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | TA 98 | | TA 1538 | | TA 100 | | TA 1535 | | TA 1537 | |
| | | -S9 | +S9 | -S9 | +S9 | -S9 | +S9 | -S9 | +S9 | -S9 | +S9 |
| DMSO-Coal Soxhlet Ex. | 100 | 28 | 43 | 1 | 21 | 118 | 146 | 47 | 51 | 8 | 19 |
| DMSO-ESP Ash | 100 | 28 | 43 | 1 | 21 | 118 | 146 | 7 | 15 | 8 | 19 |
| DMSO-Pulverized Coal | 100 | 23 | 28 | - | 19 | 175 | 194 | 7 | 15 | 6 | 11 |
| DMSO-Sluice Water | 100 | 35 | 51 | 2 | 11 | 115 | 113 | 33 | 37 | 6 | 24 |
| DMSO-Coal Leachate | 100 | 12 | 30 | - | 19 | 175 | 194 | - | 12 | 6 | 11 |

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[a] Average number of reventants from 3 replicate plates per dose.

## AMES ASSAYS

Table GJ-8. Strain Control - Ranges of Spontaneous Revertants

| | | Strain | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | TA 98 | | TA 1538 | | TA 100 | | TA 1535 | | TA 1537 | |
| Sample | Amount µL/plate | -S9 | +S9 | -S9 | +S9 | -S9 | +S9 | -S9 | +S9 | -S9 | +S9 |
| DMSO | 100 | 14-28 | 20-43 | 1-18 | 19-25 | 118-155 | 146-204 | 7-65 | 15-51 | 6-13 | 9-20 |
| $H_2O$ | 100 | 11-35 | 15-52 | 2-17 | 10-19 | 115-175 | 113-194 | 33-65 | 12-37 | 4-6 | 9-24 |
| Bacteria Only | 100 | 8 - 16 | | 5 - 12 | | 69 - 140 | | 2 - 23 | | 2 - 15 | |

Note: Ranges for background spontaneous revertants are from 4-5 runs.

or the base pair strains (TA 1535 and TA 100). In most tests the highest dose of 50 μL/ plate results in a cytotoxic reduction in the number of revertants. Since the coal leachate even when concentrated was not mutagenic, the toxicity ranking is "not detectable". The sluice water was not cytotoxic even at the highest level of concentration and therefore receives the same ranking.

In the Rat Alveolar Macrophage (RAM) Assay (Tables GJ-9 through GJ-11) no inhibition of macrophage plating efficiency or viability was observed from exposure to pulverized coal and ESP ash. The "Plating Efficiency" table (Table GJ-9) shows that between 40-60 percent of the cells exposed to the test sample attached to the bottom of the well, as it also occurred in control cultures. The attached cells from replicate plates were subsequently assayed for viability by scoring the percent of cells excluding trypan blue stain. The "RAM Cell Viability" table demonstrates that neither type of sample affected the percent of viable macrophage cells as compared to controls. There was, on the other hand, a dose response relationship for the cadmium chloride positive control. In support of the above observations the adenosine triphosphate (ATP) content of macrophage cells was measured enzymatically and found to be consistent with the above studies (see Table GJ-11).

The Chinese Hamster Ovary (CHO) Cell Cytotoxicity Assay was positive for the Conesville coal leachate and the response was dose-related. Sluice water from this boiler was only mildly toxic and there was no clear cut dose response relationship for those samples as compared to the cadmium chloride positive control.

The Rat Acute Oral Study indicates that all samples at 10 g/Kg and 10 mL/Kg were nontoxic, in that no animals died at these levels which were the highest doses administered.

## Aquatic Study Summary

### Conesville Samples

The sluice water had little effect on the test organisms, while the ash and coal leachates caused significant effects in all three tests. Several problems arose with the coal leachate sample. The barrel roller used to obtain the leachate malfunctioned, so the exact time of leaching was not known. There was not enough sample to run a new batch, so the leachate of the sample was used. During testing, the controls for the *Daphnia* showed greater than 10 mortality, which invalidates the test. This test was used to narrow the toxicity range, however, and the definitive test was repeated with satisfactory results. Due to technical error, the proposed revised Level 1 procedures (Reference 1) were instituted for the testing of the coal leachate sample. The procedural differences for the fish and *Daphnia* tests are minimal, and cause no problems in data interpretation. The algal test was run for five days instead of four, which may be a problem. However, the primary

TABLE GJ-9

## PLATING EFFICIENCY (PERCENT CELLS ATTACHED) OF EXPOSED RAT ALVEOLAR MACROPHAGE CELLS IN VITRO

| Sample | Concentration (μg/mL) | Cell Number | | TOTAL (Total Cells)* ($x10^{-4}$) | Plating Efficiency (% Cells Attached) |
|---|---|---|---|---|---|
| | | Media ($x10^{-4}$) | Attached ($x10^{-4}$) | | |
| Control | - | 4.2 | 2.9 | 7.1 (9.7) | 41 |
| $CdCl_2$ | 0.183 | 4.5 | 4.0 | 9.5 (8.0) | 42 |
| $CdCl_2$ | 1.83 | 4.4 | 4.3 | 12.0 (12.0) | 62 |
| $CdCl_2$ | 9.15 | 7.1 | 5.1 | 12.0 (15.0) | 42 |
| $CdCl_2$ | 18.3 | 5.7 | 6.2 | 12.0 (17.0) | 52 |
| $CdCl_2$ | 183.3 | 5.4 | 7.7 | 13.0 (16.0) | 59 |
| Pulverized Coal (Conesville) | 1000 | 5.3 | 3.3 | 8.6 (12.0) | 38 |
| | 500 | 5.5 | 3.9 | 9.4 (12.0) | 42 |
| | 100 | 5.2 | 3.8 | 9.0 (12.0) | 42 |
| | 50 | 6.1 | 3.4 | 9.5 (10.0) | 36 |
| | 10 | 5.3 | 3.3 | 8.6 ( - ) | 38 |
| ESP Ash (Conesville) | 1000 | 7.3 | 4.3 | 12.0 (11.0) | 37 |
| | 500 | 6.0 | 4.8 | 11.0 (12.0) | 44 |
| | 100 | 6.6 | 5.1 | 12.0 (12.0) | 44 |
| | 50 | 6.8 | 4.6 | 11.0 (14.0) | 40 |
| | 10 | 6.7 | 5.3 | 11.0 (10.0) | 44 |

*The number in parenthesis is the total number of cells from a separate well used as a control for loss of cells during analysis.

Data shows that between 40 and 60 percent of the cells exposed to the test sample attached to the bottom of the culture well. The efficiency is about equal to that of cadmium chloride controls.

## TABLE GJ-10

## RAM CELL VIABILITY

VIABILITY OF EXPOSED RAT ALVEOLAR MACROPHAGE CELLS IN VITRO EXPRESSED AS A PERCENT OF THE TOTAL NUMBER OF CELLS COUNTED

| Boiler No. | Sample Concentration (μg/mL) | Plating Efficiency (% Cells Attached) | % Viability (Trypan Blue) |
|---|---|---|---|
| Conesville | | | |
| Pulverized Coal | 1000 | 38 | 93 |
| | 500 | 42 | 97 |
| | 100 | 42 | 98 |
| | 50 | 36 | 97 |
| | 10 | 38 | 98 |
| ESP Ash | 1000 | 37 | 98 |
| | 500 | 44 | 96 |
| | 100 | 44 | 97 |
| | 50 | 40 | 97 |
| | 10 | 44 | 97 |
| Cadmium Chloride Control | 0.183 | 42 | 98 |
| | 1.83 | 62 | 96 |
| | 9.15 | 42 | 67 |
| | 18.3 | 52 | 49 |
| | 183.3 | 59 | 48 |
| | Blank | 41 | 98 |

Neither Pulverized Coal nor ESP Ash decreased uptake of trypan blue as compared to the dose related effect of cadmium chloride.

## TABLE GJ-11

## ATP CONTENT (CONESVILLE)

### ADENOSINE TRIPHOSPHATE (ATP) CONTENT OF IN VITRO EXPOSED RAT ALVEOLAR MACROPHAGE CELLS

| Test Sample | Concentration (μg/mL) | ng ATP per $10^5$ Cells Plated | % ATP of Control |
|---|---|---|---|
| ESP Ash | 1000 | 78 | 58 |
| | 500 | 156 | 116 |
| | 100 | 112 | 83 |
| | 50 | 136 | 101 |
| | 10 | 120 | 89 |
| Pulverized Coal | 1000 | 58 | 43 |
| | 500 | 100 | 75 |
| | 100 | 86 | 64 |
| | 50 | 106 | 80 |
| | 10 | 70 | 52 |
| Positive Control | | | |
| CdCl2 | 183.0 | 0 | 0 |
| | 18.3 | 0 | 0 |
| | 9.2 | 4 | 3 |
| | 1.8 | 26 | 19 |
| | 0.18 | 108 | 81 |
| Untreated Cells (Vehicle Only) | 0 | 134 | 100 |

The results of the ATP Assay are consistent with the findings in the two previous tables which show an absence of dose-response cytotoxic effect to RAM Cells for ESP Ash and Pulverized Coal.

utility of the Level 1 testing is providing preliminary environmental assessment data and aid in the identification of problem areas. When taken in this respect, the problems encountered with testing of the coal sample add no real complications in interpretation of results.

## Discussion

Ames assays of ESP fly ash from other coal fired boilers have also been negative with regard to mutagenicity (Reference 2 and 3). However, stack breaching ash in the 3 micron to sub micron size collected at a temperature of about 100°C has been shown to have moderate mutagenic activity (Reference 4). As the sampling temperature is increased the biological activity becomes less. At 350°C most of the activity is absent (Reference 2). This is probably due to the volatility of the toxicants. The published literature also suggests that the extraction procedures can be important with regard to the level of mutagenic activity observed (Reference 4). The fly ash samples used in this present study did not have a very high concentration of organic matter, based on the chemical and physical analysis of SASS samples. Therefore, the efficiency of the extraction procedures is probably a mute point.

What effect this sampling technique may have had on the level of toxicity observed in the other bioassays is not clear but it has been reported the CHO Assays tend to follow the Ames Assay with regard to positive or negative findings (Reference 5). While we did not conduct a CHO Assay using bottom ash, another study group using samples of the Conesville effluent taken the same day found low but detectable activity with regard to the material collected on the XAD-2 filter for both the Ames Assay and the CHO Assay. Since the other study group also found the Conesville bottom ash to be negative in the study, it appears reasonable to assume that our negative findings in this assay are valid.

## Conclusions

1. The samples from Conesville and from another boiler tested under this contract are somewhat similar in their biological activity as demonstrated by the seven assay methods used.

2. The negative Ames Assay response is consistent with studies of similar samples obtained under similar conditions.

3. It is assumed that at the temperatures of approximately 310°F to 325°F (the temperature just prior to the electrostatic precipitators) most of the toxicants were in the vapor phase and passed up the stack.

4. An independent study by another research group gave very similar results with regard to the Conesville samples.

5. To confirm the presence of mutagenic substances in the fly ash down stream of the ESP, some modifications of the sampling procedures will be necessary in future tests.

References For This Appendix

1. Brusick, D. J., et al. - IERL - RTP Procedures Manual: Level 1 Environmental Assessment For Biological Testing. EPA 600/8-81-024 NTIS No. PB 82-228-966, Oct. 1981 (supercedes EPA 600/7/80-079 April 1980 and EPA 600/7/77-043).

2. Kubitschek, H. E. and Luz Venta - Mutagenicity of Coal Fly Ash from Electric Power Plant Precipitators - Environmental Mutagenesis 1: 79-82 (1979).

3. Fisher, G. L., C. E. Chrisp, and O. G. Raabe - Physical Factors Affecting the Mutagenicity of Fly Ash from a Coal-Fired Power Plant - Science, Vol. 199, pp. 73-75, January, 1978.

4. Chrisp, G. L., G. L. Fisher, and J. E. Lammert - Mutagenicity of Filtrates from Respirable Coal Fly Ash - Science, Vol. 199, pp. 73-75, January, 1978.

5. Kolver, A., T. Hughes, M. B. Wilkie, D. Nichols, and T. Wolff - Bioassays for the Toxicity of Complex Environmental Mixtures - Presented at the 6th National Conference on Energy and the Environment - May, 1979, Pittsburg, PA.

The last tables in this appendix are suggested rankings of biological activity.

## TABLE GJ-12

## AMES ASSAY EVALUATION CRITERIA

| Mutagenic Activity | Solids (MEC in mg/plate) | Liquids (MEC in $\mu$L/plate) | Organic Extracts (MEC in $\mu$L/plate) |
|---|---|---|---|
| High | <0.5 | <2 | <2 |
| Moderate | 05-.5 | 2-20 | 2-20 |
| Low | .5-5 | 20-200 | 20-200 |
| Not detectable | >5 | >200 | >200 |

## TABLE GJ-13

## RAM ASSAY EVALUATION CRITERIA

| Toxicity | Solids (EC$_{50}$ in $\mu$g/mL) | Aqueous Liquids (EC$_{50}$ in $\mu$L/mL) | Nonaqueous Liquids (EC$_{50}$ in $\mu$L/mL) |
|---|---|---|---|
| High | <10 | <6 | <.2 |
| Moderate | 10 to 100 | 6 to 60 | .2-2 |
| Low | 100 to 1000 | 60 to 600 | 2-20 |
| Not detectable | >1000 | >600 | >20 |

Table GJ-14. CHO ASSAY EVALUATION CRITERIA

| Toxicity | Solids ($EC_{50}$ in μg/mL) | Aqueous Liquids ($EC_{50}$ in μL/mL) | Nonaqueous Liquids[a] ($EC_{50}$ in μL/mL) |
|---|---|---|---|
| High | <10 | <6 | <.2 |
| Moderate | 10 to 100 | 6 to 60 | .2-2 |
| Low | 100 to 1000 | 60 to 600 | 2-20 |
| Not Detectable | >1000 | >600 | >20 |

[a] Criteria for nonaqueous liquids are tentative and under evaluation.

Table GJ-15. ACUTE *IN VIVO* RODENT ASSAY EVALUATION CRITERIA

| Toxicity | Solids ($LD_{50}$ in g/kg) | Liquids ($LD_{50}$ in mL/kg) |
|---|---|---|
| High | <0.1 | <0.1 |
| Moderate | 0.1 to 1 | 0.1 to 1 |
| Low | 1 to 10 | 1 to 10 |
| Not Detectable | >10 | >10 |

Table GJ-16. DEFINITION OF TOXICITY CATEGORIES FOR AQUATIC ECOLOGICAL ASSAYS

| Assay | Activity Measured | Sample Type[a] | MAD[b] | Units | Range of $LC_{50}$ or $EC_{50}$ Concentrations | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | High | Moderate | Low | Not Detectable |
| Freshwater Fish | 96-hr $LC_{50}$[c] (lethality) | S | 1 | g/L | <0.01 | 0.01-0.1 | 0.1-1 | ND[d] at >1 |
| | | L | 100 | percent | <20 | 20-75 | 75-100 | ND at >100 |
| Freshwater Invertebrate | 48-hr $EC_{50}$[e] (immobilization) | S | 1 | g/L | <0.01 | 0.01-0.1 | 0.1-1 | ND at >1 |
| | | L | 100 | percent | <20 | 20-75 | 75-100 | ND at >100 |
| Freshwater Algae[f] | 120-hr $EC_{50}$ (growth inhibition) | S | 1 | g/L | <0.01 | 0.1-0.1 | 0.1-1 | ND at >1 |
| | | L | 80 | percent | <20 | 20-75 | 75-80 | ND at >80 |
| Marine Fish | 96-hr $LC_{50}$ (lethality) | S | 1 | g/L | <0.01 | 0.01-0.1 | 0.1-1 | ND at >1 |
| | | L | 100 | percent | <20 | 20-75 | 75-100 | ND at >100 |
| Marine Invertebrate | 96-hr $EC_{50}$ (immobilization) | S | 1 | g/L | <0.01 | 0.01-0.1 | 0.1-1 | ND at >1 |
| | | L | 100 | percent | <20 | 20-75 | 75-100 | ND at >100 |
| Marine Algae | 120-hr $EC_{50}$ (growth inhibition) | S | 1 | g/L | <0.01 | 0.1-0.1 | 0.1-1 | ND at >1 |
| | | L | 100 | percent | <20 | 20-75 | 75-100 | ND at >100 |

---

[a] S = solid, L = aqueous liquid. Nonaqueous liquids are evaluated on an individual basis due to variations in samples such as vehicle, percent organic vehicle, and percent solids.

[b] MAD = Maximum applicable dose.

[c] $LC_{50}$ = Calculated concentration expected to kill 50 percent of population.

[d] ND = Not detectable.

[e] $EC_{50}$ = Calculated concentration expected to produce effect in 50 percent of population.

[f] The MAD for routine freshwater algae testing of liquids is 80 percent rather than 100 percent as in the other tests. Evaluation of low (L) or not detectable (ND) results for this test should take into account. Samples can be retested at higher concentrations upon the recommendation of the Project Officer.

## APPENDIX K

## QUALITY ASSURANCE FOR ULTRASONIC THICKNESS DATA

The quality of the ultrasonic thickness data was checked in several ways including:

- Method Check

  Use of different methods (micrometer, caliper, span guage, ultrasonic, etc.) to measure the same group of locations to see if all methods gave the same result.

- Repeatability Check

  A single operator and ultrasonic instrument was used to measure a group of test points several times to see if the measurements were repeatable.

- Operator Check

  A variety of operators (all using the same ultrasonic instrument) measured the same group of points to see if the results depended on the operator.

- Instrument Check

  A single operator used different ultrasonic instruments to remeasure a group of test points to see if the results depended on the instrument being used.

- Surface Preparation Check

  A group of points were measured at several stages of the cleaning process to see how much metal might be removed by excessive cleaning of the tube surface.

- Evaluation of Bias

  An experiment was set up to determine what effect the cleaning and measurement proceedure had on future corrosion rate.

- Other Experiments

  Other experiments were run to evaluate the effects of:

  - Sonic coupling media and amount of couplant used.
  - Method of supporting the probe.
  - Method of calibration.
  - Calibration drift.

Some of the quality assurance (QA) data follow.

Generally, between calibrations, the calibration point drift was less than one mil, with a typical drift of ±0.5 mil. (This is about 0.2% of the measured values.)

On 11-18-79, an experiment was run to evaluate operator influence on the data. The test was performed on clean, new panels prior to their installation in the furnace walls.

About 20 different points were measured by two different operators. The results are listed below.

| TWO OPERATORS MEASURE THE SAME POINTS | | | | | |
|---|---|---|---|---|---|
| Test Location | | | Thickness Readings (mils) | | |
| Panel No. | Tube No. | Position | Operator No. 1 | Operator No. 2 | Delta = (No. 1)-(No. 2) |
| 1 | 9 | 5 | 229.2 | 228.3 | -1.3 |
| 1 | 6 | 7 | 240.2 | 241.6 | -1.4 |
| 1 | 7 | 14 | 235.4 | 235.8 | -0.4 |
| 3 | 9 | 16 | 235.1 | 234.6 | +0.5 |
| 3 | 4 | 11 | 235.7 | 235.7 | -2.0 |
| 3 | 6 | 3 | 243.3 | 243.7 | -0.4 |
| 8 | 8 | 2 | 247.8 | 246.9 | +0.9 |
| 8 | 1 | 5 | 232.6 | 232.7 | -0.1 |
| 8 | 5 | 12 | 234.6 | 234.1 | +0.5 |
| 8 | 7 | 14 | 240.3 | 240.6 | -0.3 |
| 8 | 3 | 18 | 237.5 | 235.9 | +1.6 |
| 4 | 6 | 19 | 246.2 | 245.9 | +0.3 |
| 4 | 3 | 14 | 231.6 | 230.7 | +0.9 |
| 4 | 8 | 11 | 242.0 | 241.0 | +1.0 |
| 4 | 10 | 5 | 244.6 | 244.1 | +0.5 |
| 4 | 1 | 3 | 235.0 | 234.1 | +0.9 |
| 7 | 9 | 1 | 228.4 | 229.2 | -0.8 |
| 7 | 2 | 5 | 244.2 | 245.7 | -1.5 |
| 7 | 5 | 13 | 236.8 | 236.8 | +0.0 |
| 7 | 10 | 18 | 241.3 | 240.2 | +1.1 |
| 7 | 4 | 19 | 245.5 | 243.8 | +1.7 |
| | | | AVERAGE DIFFERENCE: | | +0.08 |

This table shows that for groups of averaged data obtained under comfortable working conditions on new tubes, these two operators will produce results that, on the average, differ from each other by less than 0.0001 inch.

Another experiment (conducted on 12-18-79) was used to evaluate measurement repeatability and surface preparation procedure. This test was performed on a single point of a section of the boiler wall which had been removed so that a panel could be installed in its place. The test point was cleaned several times by motorized wire brush and was measured ten times between each brushing. The resulting data are shown below.

SAME POINT MEASURED AT SEVERAL
STAGES IN THE CLEANING PROCEDURE

| | Thickness (mils) | | |
|---|---|---|---|
| Trial Number | After Light Brush | After Heavy Brush | After Extra Heavy Brush |
| 1 | 235.6 | 236.0 | 235.6 |
| 2 | 238.4 | 236.5 | 235.6 |
| 3 | 238.6 | 236.1 | 235.8 |
| 4 | 238.9 | 236.3 | 236.0 |
| 5 | 238.1 | 236.0 | 236.0 |
| 6 | 237.7 | 236.9 | 235.6 |
| 7 | 238.3 | 236.9 | 235.8 |
| 8 | 238.4 | 236.7 | 235.5 |
| 9 | 238.1 | 236.6 | 235.5 |
| 10 | 238.6 | 236.4 | 236.2 |
| AVG | 238.1 | 236.4 | 235.8 |
| Std. Dev. | 0.9 | 0.3 | 0.2 |
| Amount of metal removed since last measurement (mils) | - | 1.7 | 0.6 |

The data show that if the tube is not brushed enough prior to measurement, the unremoved surface coating may add about 2.0 mils to the measurement. Alternatively, if the tube is brushed too much, the error is much smaller. When given the choice, it is better to clean too much than too little. This data was used to guide the operators when cleaning and preparing the tube surfaces for measurement. The data further show that readings on the same spot performed in a comfortable environment are very repeatable. In each group of measurements, most readings were within one mil of the groups average.

Another type of data-reproducibility test was performed on control panels. Thickness test control panels (TCPs) were measured both before and after a two year storage period during which they were kept in a sheltered indoor area. The following table gives the results of some of the measurements on TCP-1.

**COMPARATIVE DATA FOR A**
**VARIETY OF OPERATORS MEASURING THE SAME POINTS**

| | | TCP 1 Ultrasonic Thickness Results (Fireside)<br>Tube Wall Thickness (Mils) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Date | | 11-29-79 | 11-23-81 | 11-24-82 | 11-24-82 | 11-24-82 | 11-24-82 | Avg. of All 1982 Data | (1982) - (1981) |
| Operator | | JP | FT | RR | BM* | BM** | TK | All 1982 Data | Difference |
| Measurement Location | | *** | | | | | | | |
| Tube No. | Elevation No. | | | | | | | | |
| 5 (210) | Top | 242.2 | 243.2 | 244.4 | 243.9 | 243.6 | 243.8 | 243.8 | 1.6 |
| | 3 | 243.0 | 245.2 | 245.9 | 245.1 | 245.7 | 245.5 | 245.5 | 2.5 |
| | 2 | 240.9 | 242.4 | 242.9 | 242.8 | 243.1 | 243.0 | 242.8 | 1.9 |
| | 1 | 241.5 | 243.7 | 243.4 | 243.3 | 243.3 | 242.5 | 243.2 | 1.7 |
| | Bot | 242.2 | 243.5 | 243.7 | 242.8 | 243.0 | 243.2 | 243.2 | 1.0 |
| 6 (T-22) | Top | 235.2 | 236.5 | 236.8 | 237.8 | | 236.8 | 237.0 | 1.8 |
| | 3 | 245.1 | 247.3 | 246.6 | 246.4 | | 246.0 | 246.6 | 1.5 |
| | 2 | 231.0 | 232.2 | 231.6 | 231.4 | | 231.5 | 231.7 | 0.7 |
| | 1 | 240.9 | 241.7 | 242.3 | 241.3 | | 240.7 | 241.5 | 0.6 |
| | Bot | 243.2 | 243.8 | | 244.2 | | 243.9 | 244.0 | 0.8 |
| 8 (T-22) | Top | 243.1 | 245.2 | 244.5 | 245.5 | | 245.2 | 245.1 | 2.0 |
| | 3 | 243.3 | 244.1 | 245.2 | 243.4 | | 244.7 | 244.4 | 1.1 |
| | 2 | 225.3 | 228.4 | 226.4 | 225.2 | | 227.1 | 226.8 | 1.5 |
| | 1 | 234.6 | 237.8 | 235.1 | 235.8 | | 239.5 | 237.1 | 2.5 |
| | Bot | 237.2 | 238.7 | 240.1 | 238.7 | | 238.9 | 239.1 | 1.9 |
| 9 (210) | Top | 244.5 | 246.4 | 246.7 | 246.1 | | 245.8 | 246.3 | 1.8 |
| | 3 | 243.7 | 245.0 | 243.7 | 243.9 | | 244.3 | 244.2 | 0.5 |
| | 2 | 243.5 | 246.0 | 245.5 | 246.0 | | 245.6 | 245.8 | 2.3 |
| | 1 | 244.4 | 246.0 | 246.9 | 246.3 | | 246.4 | 246.6 | 2.0 |
| | Bot | 243.1 | 244.4 | 244.9 | 245.0 | | 245.0 | 244.8 | 1.7 |
| | AVG | 240.4 | 242.1 | 241.9 | 241.7 | | 242.0 | 242.0 | 1.6 |
| CORRECTED AVG | | 241.9 | 242.1 | 241.9 | 241.7 | | 242.0 | 242.0 | 0.1 |

* BM's 1st time

** BM's 2nd time (occurred a few minutes after his 1st time)

***Except for the bottom line, these 1979 data have not been corrected for the systematic calibration error discussed in the text. The correction would be made by adding 1.5 to the 1979 readings. This correction is clearly supported by the values shown at the bottom of the last column in this table.

These data show:

- o The correction of the 1979 data (by adding 1.5 mils) is valid (within about 0.1 mil).
- o When groups of points on new tubes are measured by various operators, the average result is very repeatable. (The five operator averages range from 241.7 to 242.1 mils. A difference of only 0.4 mils or <0.2% between the maximum and minimum values.

Data quality assurance checks, similar to those just discussed, continued during each measurement period.

After collection of the data, a calculation was made to determine if the cleaning of the tubes during the first measurement visit had biased their subsequent corrosion rate. During the second measurement visit, to facilitate the evaluation of this bias, parts of selected tubes were measured in three locations (top, middle, bottom) only a few inches apart. It was assumed that on the average, for large numbers of such locations, the thickness of each middle location would equal the average of the top and bottom positions. The middle point had been cleaned and measured two years earlier. So, if this assumption were not true, then the difference would be due to the bias caused by the first measurement.

The two methods are called the "direct," and the "indirect" methods. The single point measurement of the middle point is called the direct method of measuring its thickness. But this method could bias future measurements at that point. In the indirect method, the middle point is not touched. Its thickness is assumed to equal the average of the top and bottom points. This method will not bias future measurements at the middle point. The bias is equal to the difference between the direct and indirect results. The following table gives those results and shows that for small groups of measurement locations, the average reading by the indirect method is consistently higher (by about 1 mil) than the average result obtained by the direct method.

In other words, the process of preparing the surface of the tube for measurement may introduce a systematic error such that future direct measurements at that location may give a corrosion loss (in mils) that is erroneously low by about one mil. This one mil of lost material may be assumed to equal the sum of the metal removed during the cleaning step prior to the second measurement, and the increased corrosion loss during subsequent exposure due to the removal of the protective coating on the tube.

However, because the error is so small, no correction was made for it. Instead, when several readings were made in close spacial proximity to each other on a single tube, all readings were averaged before further analysis.

Because of this method of handling the data, the wall and panel corrosion rates reported in this document may be a few percent higher than the true rates.

## COMPARISON OF DIRECT AND INDIRECT ULTRASONIC THICKNESS DETERMINATIONS (MILS)* CONESVILLE FRONTWALL - DEC. '81

| Measurement Location (Elevation, Tube Number, and Top, Middle or Bottom) | | | Measured Thickness | Direct* = M | Indirect* = (T+B)/2 | (Indirect) - (Direct) |
|---|---|---|---|---|---|---|
| A | 69 | T | 236.5 | | | |
| | | M | 238.8 | 238.8 | 238.5 | -0.3 |
| | | B | 240.4 | | | |
| | 99 | T | 243.6 | | | |
| | | M | 243.0 | 243.0 | 244.2 | 1.2 |
| | | B | 244.8 | | | |
| | 147 | T | 246.5 | | | |
| | | M | 249.1 | 249.1 | 247.4 | -1.7 |
| | | B | 248.3 | | | |
| | 189 | T | 276.4 | | | |
| | | M | 258.0 | 258.0 | 246.85 | 8.85 |
| | | B | 257.3 | | | |
| | 219 | T | 243.0 | | | |
| | | M | 237.7 | 237.7 | 241.75 | 4.05 |
| | | B | 240.5 | | | |
| | AVERAGE | | | | | +2.42 |

For brevity, the raw data and intermediate results have been eliminated from the remainder of this table.

| | | | |
|---|---|---|---|
| B | 17 | | 0.2 |
| | 47 | | -1.85 |
| | 83 | | 6.2 |
| | 101 | | 0.45 |
| | 143 | | 1.75 |
| | 173 | | -4.25 |
| | 215 | | 3.0 |
| | AVG. | | +0.79 |
| C | 16 | | 1.5 |
| | 58 | | 4.35 |
| | 106 | | 2.25 |
| | 130 | | 1.85 |
| | 172 | | 0.7 |
| | 198 | | -2.0 |
| | 226 | | -5.15 |
| | AVG. | | +0.5 |

(Continued)

## COMPARISON OF DIRECT AND INDIRECT
## ULTRASONIC THICKNESS DETERMINATIONS (MILS)*
## CONESVILLE FRONTWALL - DEC. '81 (CONTD.)

| Measurement Location (Elevation, Tube Number, and Top, Middle or Bottom) | Measured Thickness | Direct* = M | Indirect* = (T+B)/2 | (Indirect) - (Direct) |
|---|---|---|---|---|
| 13 | | | | 0.65 |
| 55 | | | | -2.7 |
| 103 | | | | 1.7 |
| D 133 | | | | 0. 8 |
| 163 | | | | 11.05 |
| 207 | | | | 0.15 |
| 227 | | | | -0.2 |
| AVG. | | | | +1.64 |
| 18 | | | | 0.55 |
| 60 | | | | 0.75 |
| 102 | | | | 1.55 |
| E 132 | | | | 1.15 |
| 168 | | | | -0.9 |
| 210 | | | | 0.3 |
| AVG. | | | | +0.57 |
| 26 | | | | 4.75 |
| 62 | | | | -1.7 |
| F 104 | | | | -0.3 |
| 182 | | | | 2.5 |
| 218 | | | | -0.2 |
| AVG. | | | | +1.01 |
| GRAND AVG. | | | | +1.16 |

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*Direct readings are single point measurements, made only at the location of interest. Indirect readings are the average of two readings; one obtained by cleaning and measuring a point a few inches above the point of interest, and the other a few inches below the point of interest. In this way, the point of interest is left undisturbed, and future corrosion will not be influenced by the process used to measure it. In a few cases, in order to evaluate the methods, both the direct and indirect methods were used. Those cases from the front wall are listed here. The three points are named "top, middle, and bottom" (T, M, B). Direct = M, Indirect = (T+B)/2.

# APPENDIX L

## ANALYSIS OF SLAG DEPOSITS FROM CORROSION COUPONS

Several samples of slag deposits were removed from selected corrosion probe coupons (also called test rings) and submitted for chemical analysis.

The results are reported on the following pages.

## *** REPORT OF ELEMENTAL ANALYSIS ***

DATE: 81/03/17.

PROJECT NO. 900-195

XR# 8284

KDL #4916 Deposit from Test Ring E-3

| ELEMENT | CONC.(PCT) | OXIDE | CONC.(PCT) |
|---|---|---|---|
| MG | .17 | MGO | .282 |
| AL | 5.59 | AL203 | 10.56 |
| SI | 10.63 | SI02 | 22.738 |
| P | .035 | P205 | .08 |
| S | .64 | S03 | 1.597 |
| K | .38 | K20 | .458 |
| CA | 1.56 | CAO | 2.182 |
| BA | .058 | BAO | .065 |
| TI | .29 | TI02 | .484 |
| CR | .05 | CR203 | .073 |
| MN | .099 | MNO | .128 |
| FE | 42.78 | FE203 | 61.133 |
| ZN | .058 | ZNO | .072 |
| PB | .083 | PBO | .089 |
| SR | .029 | SRO | .034 |
| MO | .0053 | MO03 | .008 |
| TOTAL= | 62.4573 | TOTAL= | 99.983 |

H.F. Yankov

H.F.YANKOV
KDL X-RAY LAB.

*** REPORT OF ELEMENTAL ANALYSIS

DATE: 81/03/17.

PROJECT NO. 900-195

XR# 8284

KDL #4916 Deposit from Test Ring E-3

| ELEMENT | CONC.(PCT) |
|---|---|
| H | < .1 |
| C | .59 |
| N | < .1 |
| TOTAL= | .59 |

CHN ANALYSIS PERFORMED ON PERKIN-ELMER MOD. 240

H.F. Yankov

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*** REPORT OF ELEMENTAL ANALYSIS ***

DATE: 81/03/17.

PROJECT NO. 900-195

XR# 8285

KDL #4917 Deposit From Test Ring E-9

| ELEMENT<br>******* | CONC.(PCT)<br>************ | OXIDE<br>***** | CONC.(PCT)<br>************ |
|---|---|---|---|
| NA | .79 | NA2O | 1.065 |
| AL | 3.89 | AL2O3 | 7.348 |
| SI | 7.4 | SIO2 | 15.829 |
| P | .022 | P2O5 | .05 |
| S | .55 | SO3 | 1.373 |
| K | .28 | K2O | .337 |
| CA | .82 | CAO | 1.147 |
| BA | .047 | BAO | .052 |
| TI | .21 | TIO2 | .35 |
| CR | .036 | CR2O3 | .053 |
| MN | .079 | MNO | .102 |
| FE | 48.64 | FE2O3 | 69.507 |
| SR | .012 | SRO | .014 |
| TOTAL= | 62.776 | TOTAL= | 97.227 |

H.F. Yankov

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### *** REPORT OF ELEMENTAL ANALYSIS ***

DATE: 81/03/17.

PROJECT NO. 900-195

XR# 8285

KDL #4917 Deposit from Test Ring E-9

| ELEMENT<br>******* | CONC. (PCT)<br>************ |
|---|---|
| H | < .1 |
| C | .45 |
| N | < .1 |
| TOTAL= | .45 |

CHN ANALYSIS PERFORMED ON PERKIN-ELMER MOD. 240

H.F. Yankov
H.F.YANKOV
KDL X-RAY LAB.

*** REPORT OF ELEMENTAL ANALYSIS ***

DATE: 81/03/17.

PROJECT NO. 900-195

XR# 8286

KDL #4918 Deposit from Test Ring E-13

| ELEMENT | CONC.(PCT) | OXIDE | CONC.(PCT) |
|---|---|---|---|
| ******* | ************ | ***** | ************ |
| NA | .72 | NA2O | .971 |
| MG | .14 | MGO | .232 |
| AL | 3.45 | AL2O3 | 6.517 |
| SI | 6.38 | SIO2 | 13.647 |
| P | .046 | P2O5 | .105 |
| S | .7 | SO3 | 1.747 |
| K | .27 | K2O | .325 |
| CA | .74 | CAO | 1.035 |
| BA | .038 | BAO | .042 |
| TI | .18 | TIO2 | .3 |
| CR | .036 | CR2O3 | .053 |
| MN | .076 | MNO | .098 |
| FE | 51.01 | FE2O3 | 72.893 |
| PB | .042 | PBO | .045 |
| TOTAL= | 63.828 | TOTAL= | 98.01 |

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** REPORT OF ELEMENTAL ANALYSIS ***

ATE:  81/03/17.

ROJECT NO. 900-195

R# 8286

DL #4918    Deposit from Test Ring E-13

ELEMENT            CONC.(PCT)
*******           ************

H                  < .1
C                    .36
N                  < .1

TOTAL=               .36

CHN ANALYSIS  PERFORMED ON PERKIN-ELMER  MOD. 240
                                         H.F. Yankov
                                         H.F.YANKOV
                                         KDL X-RAY LAB.
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## *** REPORT OF ELEMENTAL ANALYSIS ***

DATE: 81/03/17.

PROJECT NO. 900-195

XR# 8287

KDL #4919 Deposit from Test Ring E-17

| ELEMENT | CONC.(PCT) | OXIDE | CONC.(PCT) |
|---|---|---|---|
| ******* | ************ | ***** | ************ |
| NA | .56 | NA2O | .755 |
| MG | .14 | MGO | .232 |
| AL | 4.34 | AL2O3 | 8.198 |
| SI | 8.32 | SIO2 | 17.796 |
| P | .03 | P2O5 | .069 |
| S | 2.07 | SO3 | 5.167 |
| K | .32 | K2O | .386 |
| CA | 1.01 | CAO | 1.413 |
| BA | .064 | BAO | .071 |
| TI | .25 | TIO2 | .417 |
| CR | .031 | CR2O3 | .045 |
| MN | .1 | MNO | .129 |
| FE | 44.23 | FE2O3 | 63.205 |
| SR | .023 | SRO | .027 |
| TOTAL= | 61.488 | TOTAL= | 97.91 |

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### *** REPORT OF ELEMENTAL ANALYSIS ***

DATE: 81/03/17.

PROJECT NO. 900-195

XR# 8287

KDL #4919 Deposit from Test Ring E-17

| ELEMENT | CONC.(PCT) |
|---|---|
| ******* | ************ |
| H | < .1 |
| C | .6 |
| N | < .1 |
| TOTAL= | .6 |

CHN ANALYSIS PERFORMED ON PERKIN-ELMER MOD. 240

H.F. Yankov
H.F.YANKOV
KDL X-RAY LAB.

### *** REPORT OF ELEMENTAL ANALYSIS ***

DATE: 81/03/17.

PROJECT NO. 900-195

XR# 8288

KDL #4920 Deposit from Test Ring E-23

| ELEMENT | CONC.(PCT) | OXIDE | CONC.(PCT) |
|---|---|---|---|
| ******* | ************ | ***** | ************ |
| NA | .85 | NA2O | 1.146 |
| MG | .13 | MGO | .216 |
| AL | 3.76 | AL2O3 | 7.103 |
| SI | 6.95 | SIO2 | 14.866 |
| P | .012 | P2O5 | .027 |
| S | .45 | SO3 | 1.123 |
| K | .3 | K2O | .361 |
| CA | .79 | CAO | 1.105 |
| BA | .035 | BAO | .039 |
| TI | .21 | TIO2 | .35 |
| CR | .034 | CR2O3 | .05 |
| MN | .16 | MNO | .207 |
| FE | 51.34 | FE2O3 | 73.365 |
| PB | .083 | PBO | .089 |
| SR | .017 | SRO | .02 |
| TOTAL= | 65.121 | TOTAL= | 100.067 |

H. F. Yankov
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KDL X-RAY LAB.

*** REPORT OF ELEMENTAL ANALYSIS ***

DATE: 81/03/17.

PROJECT NO. 900-195

XR# 8288

KDL #4920 Deposit from Test Ring E-23

| ELEMENT | CONC.(PCT) |
|---|---|
| ******* | ************ |
| H | < .1 |
| C | .49 |
| N | < .1 |
| TOTAL= | .49 |

CHN ANALYSIS PERFORMED ON PERKIN-ELMER MOD. 240

H.F. Yankov
H.F.YANKOV
KDL X-RAY LAB.

# APPENDIX M

## 30-DAY CEM TEST
## SUPPLEMENTAL INFORMATION

## EXPERIMENTAL PROCEDURES FOR THE 30-DAY TESTS

The test boiler, Unit 5 of the Conesville Generating Station of the Columbus and Southern Ohio Electric Co., is rated at 410 megawatts electrical generating capacity. The boiler is a Combustion Engineering pulverized coal-fired unit designed for firing midwestern bituminous coal. The steam flow at rated capacity is 830 MW (thermal) 2,833 x $10^3$ lb/hr. During these 30-day tests, flue gas was sampled continuously from the flue duct, just upstream of the air heater.

Two 30-day tests were performed on the Conesville boiler (Oct.-Nov. 1980, and May-June 1981). During each test, boiler load was recorded along with a semi-continuous record (once every four seconds) of stack emissions. Also, at periodic intervals, the performance (zero and span drift, response time, accuracy, etc.) of each continuous emission monitor was evaluated in accord with EPA procedures to ensure good performance and quality data. (Of course, as the researchers became familiar with the test unit, the amount of data increased. Hence, the reader will notice that there is more data and analysis for test No. 2 than for No. 1.) This section presents a description of the instrumentation used to measure the gaseous emissions, the test procedures, and the techniques for certifying the continuous monitor system.

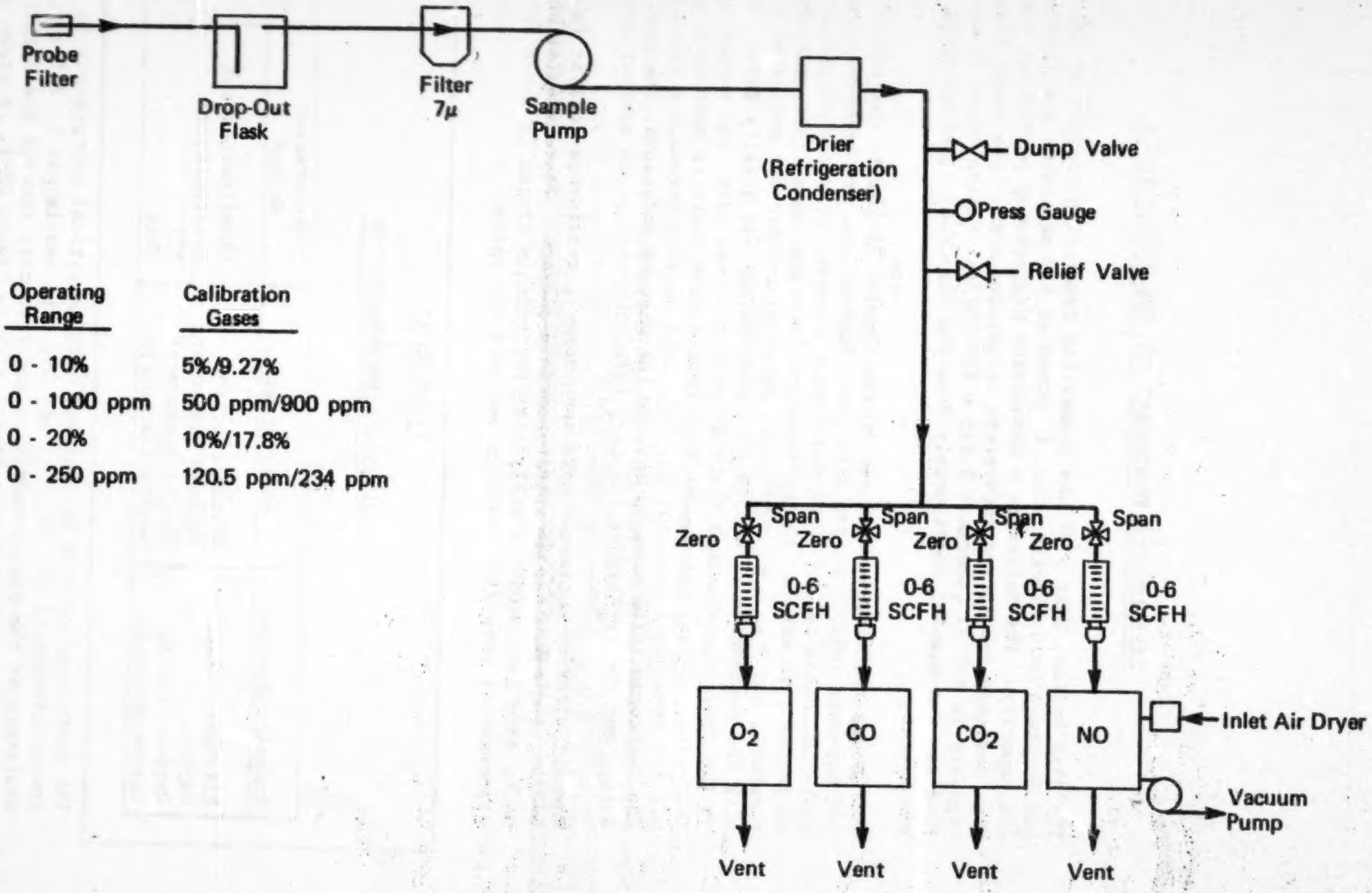
The emissions measurements were made using a continuous monitor fabricated by KVB, and assembled as a transportable package. Gaseous emission measurements were made with the analytical instruments listed in Table GM-1. All measurements were made and reported on a dry basis.

TABLE GM-1

ANALYTICAL INSTRUMENTATION

| Emission Species | Manufacturer | Measurement Method | Model No. |
|---|---|---|---|
| Nitrogen Oxides | Thermo Electron | Chemiluminescent | 10BR |
| Oxygen | Beckman Instrument | Polarographic | 742 |
| Carbon Dioxide | Horiba Instrument | NDIR | PIR-2000 |
| Carbon Monoxide | Horiba Instrument | NDIR | PIR-2000 |

The continuous monitor is equipped with analytical instruments to measure concentrations of NO, CO, $CO_2$, and $O_2$. The sample gas is delivered to the analyzers at the proper condition and flow rate through the sampling and conditioning system shown schematically in Figure GM-1. A probe with a 0.7-micrometer sintered stainless steel filter was installed in the stack to sample the flue gas. The following paragraphs describe the analytical instrumentation.



| Instrument | Operating Range | Calibration Gases |
|---|---|---|
| $O_2$ | 0 - 10% | 5%/9.27% |
| CO | 0 - 1000 ppm | 500 ppm/900 ppm |
| $CO_2$ | 0 - 20% | 10%/17.8% |
| NO | 0 - 250 ppm | 120.5 ppm/234 ppm |

FIGURE GM-1

SCHEMATIC OF CONTINUOUS MONITOR SAMPLING AND CONDITIONING SYSTEM

## Nitrogen Oxides

The oxides of nitrogen monitoring instrument used was a Thermo Electron chemiluminescent nitric oxide analyzer. The operational basis of the instrument is the chemiluminescent reaction of NO and $O_3$ to form $NO_2$ in an excited state. The resulting chemiluminescence is monitored through an optical filter by a high sensitivity photomultiplier tube, the output of which is electronically processed so it is linearly proportional to the NO concentration.

Air for the ozonator is drawn from ambient through an air dryer and a 10-micrometer filter element. Flow control for the instrument is accomplished by means of a small bellows pump mounted on the vent of the instrument downstream of a separator which insures that no water collects in the pump.

The basic analyzer is sensitive only to NO molecules. To measure $NO_x$ (i.e., NO + $NO_2$), the $NO_2$ is first converted to NO. This is accomplished by a converter which is included with analyzer. The conversion occurs as the gas passes through a thermally insulated, resistance heated, stainless steel coil. With the application of heat, $NO_2$ molecules in the sample gas are reduced to NO molecules, and the analyzer then reads $NO_x$. $NO_2$ is obtained by the difference in readings obtained with and without the converter in operation.

### Specifications for the Nitrogen Oxides Analyzer

Accuracy: 1% of full scale
Span drift: ± 1% of full scale in 24 hours
Zero drift: ± 1 ppm in 24 hours
Power requirements: 115 ± 10V, 60 Hz, 1000 watts
Response: 90% of F.S. in 1 sec ($NO_x$ mode); 0.7 sec (NO mode)
Output: 4-20 ma
Sensitivity: 0.5 ppm
Linearity: ± 1% of full scale
Vacuum detector operation
Ranges: 2.5, 10, 25, 100, 250, 1000, 2500, 20,000 ppm F.S.

Only the NO concentration was measured during this program. Because of the added complexity of heated sample lines and controllers necessary for measuring $NO_2$ and the small percentage of $NO_2$ in the flue gas, based on previous tests (Ref. 1, 2 and 3), it was decided that only NO measurement was necessary. Therefore, an unheated sample line was installed, and the moisture was removed from the sample gas by a dropout flask and a refrigerated condenser.

## Carbon Monoxide and Carbon Dioxide

Carbon monoxide (CO) and carbon dioxide ($CO_2$) concentrations were measured by Horiba Instruments PIR-2000 short-path-length nondispersive infrared analyzers. These instruments measure the diffference in infrared energy absorbed from energy beams passed through a reference cell (containing a gas selected to have minimal absorption of infrared energy in the wave length absorbed by the gas component of interest) and a sample cell through which the sample gas flows continuously. The differential absorption appears as a reading on a scale of zero to 100% and is then related to the concentration of the species of interest by calibration curves supplied with the instrument. A linearizer was supplied with the CO analyzer to provide a linear output over the range of interest. The operating ranges for the CO analyzer are zero to 500, zero to 1000, and zero to 2000 ppm, and the ranges for the $CO_2$ analyzer are zero to 5, zero to 10, and zero to 20%.

### Specifications for the Carbon Monoxide and Carbon Dioxide Analyzers

Accuracy: 1% of full scale
Repeatability: ± 0.5% of full scale
Zero drift: ± 1% of full scale in 24 hours
Span drift: ± 1% of full scale in 24 hours
Response time: selectable - 90% of full scale in 0.5, 1.2, 3, or 5 seconds
Power requirements: 115 VAC ± 10%, 60 Hz
Warm up time: 30 minutes
Output: 0-10 MV

## Oxygen

A Beckman Model 742 oxygen analyzer was used to continuously determine the oxygen content of the flue gas sample. The oxygen measuring element contains a silver anode and gold cathode that are protected from the sample by a thin membrane of Teflon. An aqueous KCL solution is retained in the sensor by the membrane and serves as an electrolytic agent. As Teflon is permeable to gases, oxygen will diffuse from the sample to the cathode in the following oxidation-reduction reaction:

Cathode reaction: $O_2 + 2H_2O + 4e \rightarrow 4OH$
Anode reaction: $4Ag + 4Cl \rightarrow 4AgCl + 4e$

With an applied potential between the cathode and anode, oxygen will be reduced at the cathode causing a current to flow. The magnitude of this current is proportional to the partial pressure of oxygen present in the sample. The instrument has operating ranges of zero to 1%, zero to 10%, and zero to 25% oxygen.

### Specifications for the Oxygen Analyzer

Accuracy: ± 1% of full scale or ± 0.05% $O_2$, whichever is greater
Sensor stability: ± 1% of full scale per 24 hours
Response time: 90% in 20 seconds
Output: 0-10 MV
Power requirements: 120/110 VAC, 60 Hz

## Data Recording

The measurements from the gaseous analyzers were continuously recorded on dual-pen strip chart recorders, an automatic data logger and magnetic tape cassettes. These instruments are described in the following paragraphs:

- Strip-Chart Recorders

  Three dual-pen Linear Instruments Corp. Model 432 strip chart recorders were installed in the continuous monitor. Two recorders were used to record the analyzer outputs and the third recorder was used as a back-up.

  ### Specifications for the Strip-Chart Recorders

  Recorder type: Null balance DC Servo
  Input span: Base span 1 mV to 100 VDC
  Accuracy: ± 0.5 percent
  Temperature stability: 1 μV/°C
  Response: 0.5 sec over full 250 mm span
  Zero: Right hand zero, 100% zero suppression
  Chart drive: 12 speeds
  Chart width: Two channel crossover: 250 mm
  Dimensions: 17.8 cm (7") H x 44.5 cm (17.5") W x 30.5 cm (12") D
  Power requirements: 115/230 VAC 60 Hz: <20 watts
  Weight: 11.4 kg (25 lb)

- Automatic Data Logger

  The analyzer outputs were continuously recorded on a Monitor Lab Model 9300 microprocesor-based data logger. This data logger has the capability of recording 40 input channels. The data for each analyzer was printed, along with the exact time and date, in a digital form on a built-in inkless printer. The data logger was programmed to sample each analyzer every 4 seconds and print out averages every 15 minutes. The digital printout lists the number of samples in each averaging period.

  ### Specifications for the Automatic Data Logger

  Inputs: Up to 40 channels of analog voltage, current and temperature inputs can be accommodated in the mainframe.
  Voltage ranges: ± 30,000 mV, ± 300.00 mV, ± 3.000 V, ± 12.000 V, Autorange
  Resolution: 1 μV on 30.000 mV range
  Accuracy: ± 0.02% Reading ± 0.01% range ± 1 digit
  Power: 115/230 V ± 10%, 60 Hz, <125 watts
  Dimensions: 18 cm (H) x 48.3 cm (W) x 56 cm (D) (17" x 19" x 22")
  Weight: 18.2 kg (40 lb)

- **Digital Tape Cassette Recorder**

  Data from the automatic data logger were recorded on magnetic tape cassettes with a Techtran Model 816 recorder. This recorder stored all gaseous emissions data on tape for subsequent use.

  **Specifications for the Tape Cassette Recorder**

  Storage capacity: 145,000 characters per cassette
  Storage media: Phillips-type magnetic tape cassette
  Tape speed: 20 ips read/write; 120 ips rewind
  Size: 13 cm (H) x 18 cm (W) x 28 cm (D) (5" x 7-1/4" x 11")
  Weight: 2.7 kg (6 lb)
  Temperature range: 10° to 40°C
  Power requirements: 115 VAC 47-63 Hz; 30 watts

Gaseous emissions data were measured continuously and recorded on an automatic data logger, as well as on strip-chart recorders and a magnetic tape recorder as already described. All gaseous emissions measurements were made and reported on a dry basis. Fifteen minute averages (about 225 data points for each instrument) of NO, $O_2$ $CO_2$, and CO emissions were recorded on tape, while strip-chart records were used to verify the data logger tapes and to fill in any gaps in the data from the automatic data logger. A daily log of emissions and boiler operating data was kept by a technician on-site. These data were later fed to a computer for data analysis.

The Conversion of $NO_x$ units from ppm to ng/J was made using the procedure outlined in the Federal Register (Vol. 44, No. 113/Monday, June 11, 1979, paragraph 5.3, "Calculation of Emission Rate"). The NO emission rates for this unit were calculated from the following equation:

$$E = (C_d)(F_d)\left(\frac{20.9}{20.9 - \%\ O_2}\right).$$

Where:

$E$ = pollutant emission rate, ng/J
$C_d$ = pollutant concentration, ng/scm
To convert from ppm ($NO_x$) to ng/scm, multiply by $1.912 \times 10^6$.
$F_d$ = fuel firing factor (i.e., the ratio of gas volume released during combustion divided by the heat content of the fuel) dscm/J. $F_d$ for bituminous coal is $2.63 \times 10^{-7}$ dscm/J.
The subscript d represents a dry measurment of gaseous concentration.

NO emissions were measured on a dry basis and the emission rates reported herein were calculated based on the molecular weight of $NO_2$ ($NO_x$ as $NO_2$). The boiler steam load is tabulated in units of thermal megawatts (the SI equivalent of Btu/hr). Thermal megawatts ($MW_{TH}$) were calculated by multiplying the boiler steam flow, lb/hr (obtained from the daily log sheet) by the enthalpy of the steam (approximately $10^3$ Btu/lb) and by the conversion factor for Btu/hr to watts, 0.293. Note that megawatts thermal is the boiler steam load in SI energy units, and should not be confused with the gross electrical generator output which is also expressed in megawatts.

After the preliminary screening, the data were fed to the computer and a listing of 15-minute averages was compiled. Each 15-minute average was corrected to 3 percent $O_2$ basis and these data were then used to compile 24-hour averages for the entire test period. A partial listing of the 15-minute averages may be found at the end of this appendix.

## CONTINUOUS MONITOR CERTIFICATION TESTS

Following shipment to the test site, the monitoring system was installed and certification tests were performed according to EPA's Performance Specification 2 (PS2) and 3 (PS3), 40 CFR 60. These specifications establish minimum performance criteria that the NO monitoring system must meet in terms of eight parameters: accuracy, calibration error, two- and 24-hour zero drifts, two- and 24-hour calibration drifts, response time, and operational period.

For the first test, the continuous monitor system was installed and instruments were initially calibrated on October 8, 1980 (for the second test, the corresponding date was May 5, 1981). The monitor performance certification for the first test began on October 9, 1980, and, for the second test began on May 6, 1981 and was completed May 14, 1981. Schedules of daily events for the certification tests are presented in Tables GM-2 and GM-3.

Certified calibration gases were obtained from Scott Environmental Technology, Inc. The calibration gases included zero gas as well as 50% and 90% (of full scale) span gases for the NO, $CO_2$, CO, and $O_2$ analyzers. In addition to the certified analysis supplied by the vendor, flask samples of the NO calibration gas were sent to an independent laboratory for analysis.

Relative accuracy tests for the NO analyzer were performed as outlined in PS2 using EPA Reference Method 7 (phenoldisulfonic acid [PDS] colorimetric) as the standard. Generally, nine sets of three PDS flasks (27 in all) were collected at one hour intervals at the beginning of each 30-day test, and the process was repeated at the end of each 30-day test period. All sample flasks were returned to an independent laboratory for analysis (4 x 27 = 108 samples total). The $NO_x$ span gases (various blends of NO in $N_2$) were also analyzed by the PDS method, and the results are shown in Table GM-4. The results of the relative accuracy determination showed that the NO instrument exceeded the accuracy requirements of PS2.

During these tests, the researchers noticed that the PDS analyses give consistently higher $NO_x$ values than did the NO monitor. This is primarily due to two factors. First, the PDS analyses report $NO_x$ as a combination of both NO and $NO_2$, while the monitor reports only NO. However, monitoring $NO_2$ (<5% of the total $NO_x$ in most boilers) requires heated sample lines to prevent water condensation (since $NO_2$ is soluble in condensed water). The added cost and complexity needed to measure the small amount of $NO_2$ expected, was determined to be unnecessary and only NO was measured by the monitor.

## TABLE GM-2

## SCHEDULE OF CERTIFICATION TEST EVENTS
## FIRST 30-DAY CEM TEST

| Date | Time | Event |
|---|---|---|
| 10-9-80 | 900 | Initial 24 hour zero and span reading<br>Initial 2 hour zero and span reading |
| 10-9-80 | 1100 | 1st 2 hour zero and span drift point |
| 10-9-80 | 1300 | 2nd 2 hour zero and span drift point |
| 10-9-80 | 1500 | 3rd 2 hour zero and span drift point |
| 10-9-80 | 1700 | 4th 2 hour zero and span drift point |
| 10-9-80 | 1900 | 5th 2 hour zero and span drift point |
| 10-9-80 | 2100 | 6th 2 hour zero and span drift point |
| 10-10-80 | 900 | 1st 24 hour zero and calibration drift point<br>Initial 2 hour zero and calibration reading |
| 10-10-80 | 1100 | 7th 2 hour zero and span drift point |
| 10-10-80 | 1300 | 8th 2 hour zero and span drift point |
| 10-10-80 | 1500 | 9th 2 hour zero and span drift point |
| 10-10-80 | 1700 | 10th 2 hour zero and span drift point |
| 10-10-80 | 1900 | 11th 2 hour zero and span drift point |
| 10-10-80 | 2100 | 12th 2 hour zero and span drift point |
| 10-11-80 | 1100 | 13th 2 hour zero and span drift point |
| 10-11-80 | 1300 | 14th 2 hour zero and span drift point |
| 10-11-80 | 1500 | 15th 2 hour zero and span drift point |
| 10-11-80 | 900 | 2nd 24 hour zero and calibration drift point |
| 10-12-80 | 900 | 3rd 24 hour zero and calibration drift point |
| 10-7-80 | 900 | Instrument response time sheets |
| 10-13-80 | 900 | 4th 24 hour zero and calibration drift point |
| 10-13-80 | 930 | 1st set of relative accuracy samples taken |
| 10-13-80 | 1030 | 2nd set of relative accuracy samples taken |
| 10-14-80 | 930 | 3rd set of relative accuracy samples taken |
| 10-14-80 | 1030 | 4th set of relative accuracy samples taken |
| 10-14-80 | 1130 | 5th set of relative accuracy samples taken |
| 10-14-80 | 1230 | 6th set of relative accuracy samples taken |
| 10-14-80 | 1330 | 7th set of relative accuracy samples taken |
| 10-14-80 | 1430 | 8th set of relative accuracy samples taken |
| 10-14-80 | 1530 | 9th set of relative accuracy samples taken |
| 10-14-80 | 900 | 5th 24 hour zero and calibration drift point |
| 10-15-80 | 900 | 6th 24 hour zero and calibration drift point |
| 10-16-80 | 900 | 7th and final 24 hour zero and calibration drift point |

## TABLE CM-3

## SCHEDULE OF CERTIFICATION TEST EVENTS
## SECOND 30-DAY CEM TEST

| Date | Time | Event |
|---|---|---|
| 5-07-81 | 900 | Initial 24 hour zero and span reading |
| | | Initial 2 hour zero and span reading |
| 5-07-81 | 1100 | 1st 2 hour zero and span drift point |
| 5-07-81 | 1300 | 2nd 2 hour zero and span drift point |
| 5-07-81 | 1500 | 3rd 2 hour zero and span drift point |
| 5-08-81 | 900 | 1st 24 hour zero and calibration drift point |
| | | Initial 2 hour zero and calibration reading |
| 5-08-81 | 1100 | 4th 2 hour zero and span drift point |
| 5-08-81 | 1300 | 5th 2 hour zero and span drift point |
| 5-08-81 | 1500 | 6th 2 hour zero and span drift point |
| 5-09-81 | 900 | 2nd 24 hour zero and calibration drift point |
| | | Initial 2 hour zero and calibration reading |
| 5-09-81 | 1100 | 7th 2 hour zero and span drift point |
| 5-09-81 | 1300 | 8th 2 hour zero and span drift point |
| 5-09-81 | 1500 | 9th 2 hour zero and span drift point |
| 5-10-81 | 900 | 3rd 24 hour zero and calibration drift point |
| | | Initial 2 hour zero and calibration reading |
| 5-10-81 | 1100 | 10th 2 hour zero and span drift point |
| 5-10-81 | 1300 | 11th 2 hour zero and span drift point |
| 5-10-81 | 1500 | 12th 2 hour zero and span drift point |
| 5-11-81 | 900 | 4th 24 hour zero and calibration drift point |
| 5-11-81 | 1000 | Initial 2 hour zero and calibration reading |
| 5-11-81 | 1100 | 13th 2 hour zero and span drift point |
| 5-11-81 | 1300 | 14th 2 hour zero and span drift point |
| 5-11-81 | 1500 | 15th 2 hour zero and span drift point |
| 5-12-81 | 900 | 5th 24 hour zero and calibration drift point |
| 5-13-81 | 900 | 6th 24 hour zero and calibration drift point |
| 5-14-81 | 900 | 7th and final 24 hour zero and calibration drift point |
| 5-14-81 | 900 | Initial Relative Accuracy Test |
| 5-14-81 | 900 | 1st set of relative accuracy samples taken |
| 5-14-81 | 1000 | 2nd set of relative accuracy samples taken |
| 5-14-81 | 1100 | 3rd set of relative accuracy samples taken |
| 5-14-81 | 1300 | 4th set of relative accuracy samples taken |
| 5-14-81 | 1400 | 5th set of relative accuracy samples taken |
| 5-14-81 | 1500 | 6th set of relative accuracy samples taken |
| 5-14-81 | 1600 | 7th set of relative accuracy samples taken |
| 5-14-81 | 1700 | 8th set of relative accuracy samples taken |
| 6-01-81 | 900 | Instrument Response time sheets |
| 6-03-81 | 900 | Final Relative Accuracy Test |
| 6-03-81 | 900 | 1st set of relative accuracy samples taken |
| 6-03-81 | 1000 | 2nd set of relative accuracy samples taken |
| 6-03-81 | 1100 | 3rd set of relative accuracy samples taken |
| 6-03-81 | 1300 | 4th set of relative accuracy samples taken |
| 6-03-81 | 1400 | 5th set of relative accuracy samples taken |
| 6-03-81 | 1500 | 6th set of relative accuracy samples taken |
| 6-03-81 | 1600 | 7th set of relative accuracy samples taken |
| 6-03-81 | 1700 | 8th set of relative accuracy samples taken |

## TABLE GM-4

### Reference Method 7 (PDSA) Tests of Calibration Gas

| Date | Flask No. | Vendor Data Calibration Gas Concentration, ppm | PDSA Data Method 7 Results, ppm |
|---|---|---|---|
| **Test No. 1** | | | |
| 10/14/81 | 1488 | 234 | 306 |
| | 1457 | 234 | 391 |
| | 1420 | 234 | 251 |
| | | | Average 278 |
| 11/20/80 | 1146 | 405.5 | 442 |
| | 1437 | 405.5 | 461 |
| | 1496 | 405.5 | 450 |
| | | | Average 451 |
| **Test No. 2** | | | |
| 5/14/81 | | 405.5 | 370 |
| 6/3/81 | | 405.5 | 400 |

The other factor contributing to the discrepancy is probably the span gas mixture. Analysis of one span gas made at the start of the second 30-day test showed a variation of 8.6% from the supplier's certified value, while that same gas analyzed at the end of the second 30-day test varied by only 1.2% from the supplier's value. The mixture used for this test was NO mixed with $N_2$ as specified in the Federal Register. KVB has conducted tests that show that when $CO_2$ is present in the gas being monitored (as it is in the flue gas), the $CO_2$ will interfere slightly with the accuracy of the $NO_x$ monitor due to third body quenching unless a similar amount of $CO_2$ it also present in the calibration gas. The $NO_x$ error could be 8% when the gas being monitored contains 10% $CO_2$. Nevertheless, all relative accuracy tests showed that the NO instrument exceeded the accuracy requirements of PS2.

## THEORETICAL COMBUSTION PRODUCTS BASED ON COAL ANALYSIS

During the test program, samples of the coal were taken and submitted by KVB, to an independent laboratory for analysis. The results of these fuel analyses (presented in Table GM-5) were used to calculate theoretical combustion information. For this coal, Figure GM-2 shows the theoretical values of excess $O_2$ versus $CO_2$ for the first Conesville 30-day test. Also plotted in Figure GM-2 are the actual $O_2$ versus $CO_2$ values based on the 24-hour averages.

A linear regression analysis using all the data shown in Figure GM-2 shows that the coefficient of determination, $r^2$, was 0.68 for all the data. However, by eliminating the two points on the graph that appear to be outside the normal data scatter, the coefficient of determination was computed to be 0.91 which indicates a good fit.

For the two days containing the questionable $O_2$ averages, the linear regression of actual data in Figure GM-2 was used to determine what the $O_2$ value should have been for the measured value of $CO_2$, and that $O_2$ value was used to calculate the emission rates by use of the formula presented earlier in this appendix.

Similarly, for the second test, both $O_2$ and $CO_2$ were measured to provide redundancy in the dilution correction factor. A plot of $CO_2$ versus $O_2$ for the second test yielded a correlation coefficient, $r^2$, of 0.839, which shows good correlation. The equation for the data fit for the second CEM test is: $CO_2 = [17.43] - [(0.975)(O_2)]$.

## DATA QUALITY

During the first test, comparisons were made between the $O_2$ measured at the continuous monitor and $O_2$ measured with the plant's analyzer. The plant's $O_2$ analyzer (a non-extractive type) consistently gave readings that were 3/4 to 1 percent lower than those of the KVB extractive CEM used in these tests. This difference is due primarily to the plant measuring oxygen on a wet basis and the continuous monitor measuring oxygen on a dry basis. All monitor measurements presented in this report, are on a dry basis.

## TABLE GM-3

### SUMMARY OF FUEL ANALYSES
### CONESVILLE 30-DAY TESTS (UNIT NO. 3)

|  | First 30-Day Test |  |  |  |  |  | Second 30-Day Test |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  | Analysis Report No. 71-59493 |  | Analysis Report No. 71-59492 |  | Analysis Report No. 71-61990 |  | Analysis Report No. 71-73415 |  | Analysis Report No. 71-73416 |  |
| Ultimate Analysis | As Received | Dry Basis | As Received | Dry Basis | As Received | Dry Basis | As Received | Dry Basis | As Received | Dry Basis |
| % Moisture | 12.74 | xxxxx | 12.40 | xxxxx | 7.81 | xxxxx | 12.92 | — | 8.60 | — |
| % Carbon | 53.80 | 61.65 | 54.30 | 61.99 | 64.32 | 69.77 | 57.66 | 66.21 | 65.12 | 71.25 |
| % Hydrogen | 3.69 | 4.23 | 3.69 | 4.21 | 4.47 | 4.85 | 4.14 | 4.75 | 4.62 | 5.05 |
| % Nitrogen | 0.80 | 0.92 | 1.10 | 1.26 | 0.89 | 0.96 | 0.86 | 0.99 | 1.14 | 1.25 |
| % Chlorine | 0.07 | 0.08 | 0.07 | 0.08 | 0.11 | 0.12 | 0.07 | 0.08 | 0.04 | 0.04 |
| % Sulfur | 3.75 | 4.30 | 3.81 | 4.35 | 4.03 | 4.37 | 4.05 | 4.65 | 2.88 | 3.15 |
| % Ash | 18.15 | 20.80 | 18.22 | 20.80 | 11.17 | 12.12 | 13.79 | 15.83 | 10.26 | 11.23 |
| % Oxygen (diff) | 7.00 | 8.02 | 6.41 | 7.31 | 7.20 | 7.81 | 6.51 | 7.49 | 7.34 | 8.03 |
|  | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| H (Btu/lb) | 9705 | 11122 | 9782 | 11167 | 11677 | 12666 | 10547 | 12112 | 11835 | 12949 |
|  |  |  |  |  |  |  | Date Sampled: 5/29/81 |  | Date Sampled: 6/9/81 |  |

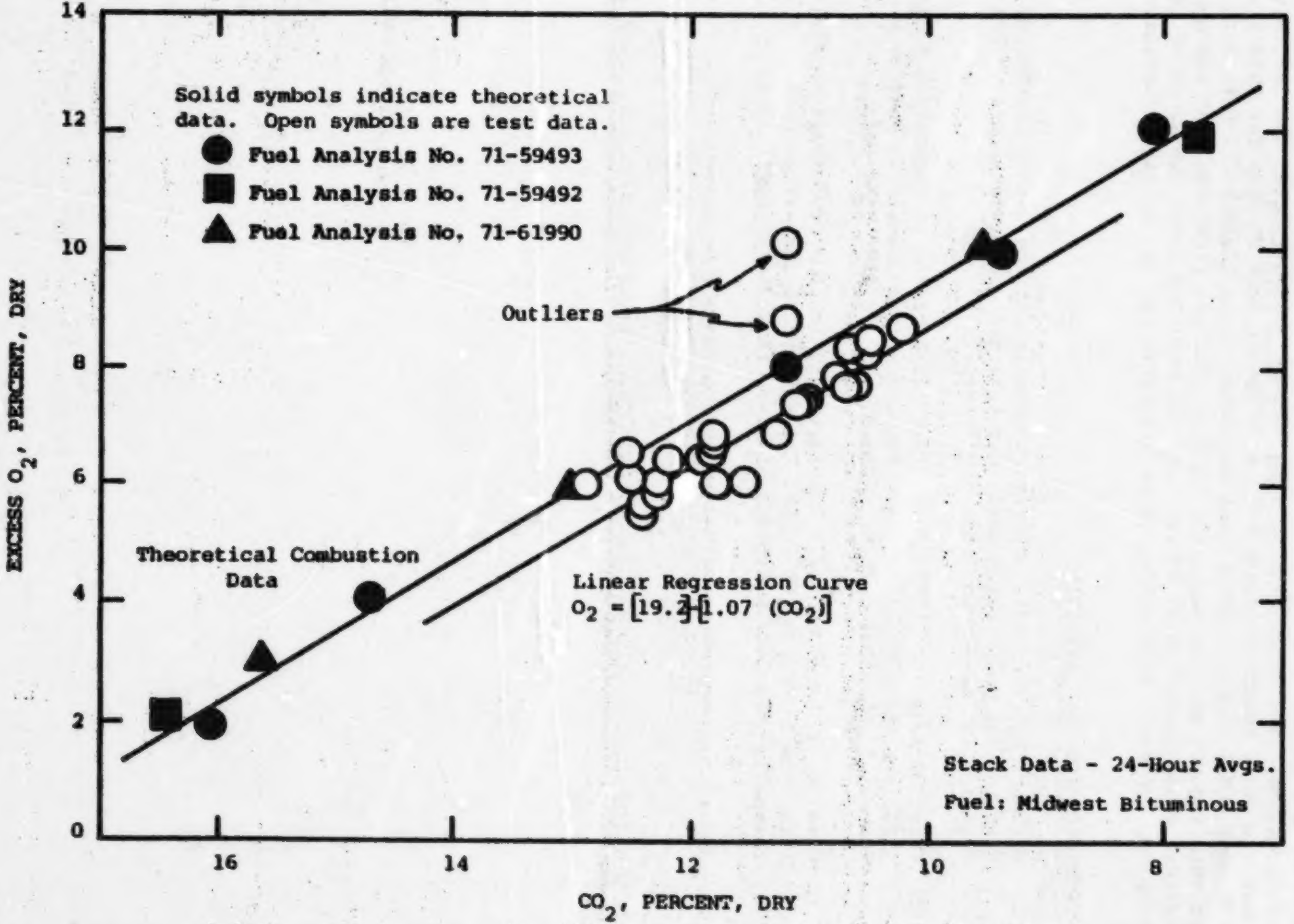


Figure GM-2. Conesville: First 30-Day CEM Test. Theoretical and actual excess oxygen ($O_2$) as a function of carbon dioxide ($CO_2$) for bituminous coal.

During the first test, in spite of redundant filtration in the sample system, the CO instrument became dirty and the readings would drift between calibrations. The technician on site cleaned and calibrated the instrument when the drift became apparent to him. However, the CO data for this first CEM test still showed a great deal of scatter (see Table F-III-4 in Part F of this report) and, as such, the CO data from the first CEM test may not be valid. (The collection of CO data was not required under the scope of this program. However, when valid, it is presented for the reader's convenience.)

## REFERENCES FOR THIS APPENDIX

1. Maloney, K. L. et al., "Systems Evaluation of the Use of Low-Sulfur Western Coal in Existing Small and Intermediate-Sized Boilers," EPA Contract No. 68-02-1863, EPA 600/7-78-153a.

2. Cato, G. A. et al., "Field Testing: Application of Combustion Modifications to Control Pollutant Emissions from Industrial Boilers - Phase I," EPA 650/2-74-078a, NTIS No. PB 238 920, June 1975.

3. Cato, G. A. et al., "Field Testing: Application of Combustion Modifications to Control Pollutant Emissions from Industrial Boilers - Phase II," EPA 600/2-76-086a, NTIS No. PB 253 500, April 1976.

# TABULATION OF 15-MINUTE CEM DATA

## SELECTED DATA FROM
## TEST NO. 2

As an example, the next few pages present data from about two days of the second thirty day test.

The last column in each of the following pages is called the "A Code" and is explained below.

| Code | | Explanation |
|---|---|---|
| A | - | Testing Begins |
| B | - | Testing Ends |
| C | - | Instrument Calibrations |
| D | - | NO Instrument Out of Service (Maintenance) |
| E | - | $O_2$ Instrument Out of Service (Maintenance) |
| F | - | $CO_2$ Instrument Out of Service (Maintenance) |
| G | - | CO Instrument Out of Service (Maintenance) |
| H | - | Boiler (Or Unit) Out of Service |
| I | - | Continuous Monitor Certification Tests |
| J | - | Continuous Monitor Out of Service (Maintenance) |
| K | - | Power Failure |

Revised 6/9/81

4

CONESVILLE UNIT 5 TEST 2
15 MIN. DATA
DRY STACK GAS CONCENTRATION

| DATE | TIME | LOAD MWTH | O2 VOL% MEAS | CO2 VOL% MEAS | CO PPMV MEAS | NO PPMV MEAS | CO PPMV 3%O2 | NO PPMV 3%O2 | CO NG/J | NO* NG/J | ACODE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5/ 5/81 | 1630 | 840.6 | 4.1 | 13.3 | 66 | 282 | 70 | 300 | 25 | 176 | A |
| 5/ 5/81 | 1645 | 841.2 | 4.1 | 18.3 | 73 | 277 | 77 | 295 | 27 | 173 | |
| 5/ 5/81 | 1700 | 841.2 | 4.2 | 13.3 | 64 | 277 | 68 | 296 | 24 | 174 | |
| 5/ 5/81 | 1715 | 841.2 | 4.1 | 13.3 | 65 | 271 | 69 | 288 | 24 | 169 | |
| 5/ 5/81 | 1730 | 841.2 | 4.1 | 13.3 | 57 | 268 | 60 | 285 | 21 | 167 | |
| 5/ 5/81 | 1745 | 844.1 | 4.2 | 13.2 | 53 | 267 | 56 | 286 | 20 | 168 | |
| 5/ 5/81 | 1800 | 844.1 | 4.2 | 13.2 | 53 | 265 | 56 | 284 | 20 | 166 | |
| 5/ 5/81 | 1815 | 844.1 | 4.1 | 13.2 | 50 | 264 | 53 | 281 | 18 | 165 | |
| 5/ 5/81 | 1830 | 844.1 | 4.2 | 13.2 | 47 | 261 | 50 | 279 | 17 | 164 | |
| 5/ 5/81 | 1845 | 842.4 | 4.2 | 13.2 | 50 | 259 | 53 | 277 | 19 | 162 | |
| 5/ 5/81 | 1900 | 842.4 | 4.3 | 13.2 | 45 | 258 | 48 | 278 | 17 | 163 | |
| 5/ 5/81 | 1915 | 842.4 | 4.2 | 13.2 | 44 | 257 | 47 | 275 | 16 | 161 | |
| 5/ 5/81 | 1930 | 842.4 | 4.2 | 13.2 | 40 | 259 | 43 | 277 | 15 | 162 | |
| 5/ 5/81 | 1945 | 838.6 | 4.2 | 13.2 | 43 | 260 | 46 | 278 | 16 | 163 | |
| 5/ 5/81 | 2000 | 838.6 | 4.3 | 13.2 | 50 | 260 | 53 | 280 | 19 | 164 | |
| 5/ 5/81 | 2015 | 838.6 | 4.2 | 13.2 | 59 | 262 | 63 | 280 | 22 | 164 | |
| 5/ 5/81 | 2030 | 838.6 | 4.2 | 13.2 | 59 | 265 | 63 | 284 | 22 | 166 | |
| 5/ 5/81 | 2045 | 839.7 | 4.2 | 13.2 | 60 | 267 | 64 | 286 | 22 | 168 | |
| 5/ 5/81 | 2100 | 839.7 | 4.2 | 13.2 | 64 | 272 | 68 | 291 | 24 | 171 | |
| 5/ 5/81 | 2115 | 839.7 | 4.2 | 13.2 | 53 | 271 | 56 | 290 | 20 | 170 | |
| 5/ 5/81 | 2130 | 839.7 | 4.3 | 13.1 | 51 | 275 | 54 | 296 | 19 | 174 | |
| 5/ 5/81 | 2145 | 842.4 | 4.2 | 13.1 | 47 | 266 | 50 | 285 | 17 | 167 | |
| 5/ 5/81 | 2200 | 842.4 | 4.3 | 13.0 | 46 | 265 | 49 | 285 | 17 | 167 | |
| 5/ 5/81 | 2215 | 842.4 | 4.2 | 13.1 | 70 | 266 | 75 | 285 | 26 | 167 | |
| 5/ 5/81 | 2230 | 842.4 | 4.2 | 13.1 | 53 | 267 | 56 | 286 | 20 | 168 | |
| 5/ 5/81 | 2245 | 718.1 | 4.7 | 12.7 | 33 | 264 | 36 | 291 | 12 | 171 | |
| 5/ 5/81 | 2300 | 718.1 | 5.2 | 12.4 | 32 | 242 | 36 | 275 | 12 | 161 | |
| 5/ 5/81 | 2315 | 718.1 | 6.3 | 11.6 | 31 | 217 | 38 | 266 | 13 | 156 | |
| 5/ 5/81 | 2330 | 718.1 | 6.4 | 11.6 | 32 | 221 | 39 | 272 | 14 | 160 | |
| 5/ 5/81 | 2345 | 475.5 | 6.3 | 11.7 | 32 | 219 | 39 | 268 | 13 | 157 | |
| 5/ 5/81 | 2400 | 475.5 | 6.5 | 11.6 | 31 | 226 | 38 | 280 | 13 | 164 | |

*As $NO_2$

5

CONESVILLE UNIT 5 TEST 2
15 MIN. DATA
DRY STACK GAS CONCENTRATION

| DATE | TIME | LOAD MWTH | O2 VOL% MEAS | CO2 VOL% MEAS | CO PPMV MEAS | NO PPMV MEAS | CO PPMV 3%O2 | NO PPMV 3%O2 | CO NG/J | NO* NG/J | ACODE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5/ 6/81 | 15 | 467.6 | 6.4 | 11.6 | 32 | 224 | 39 | 276 | 14 | 162 | |
| 5/ 6/81 | 30 | 467.6 | 6.4 | 11.6 | 31 | 223 | 38 | 275 | 13 | 161 | |
| 5/ 6/81 | 45 | 467.6 | 6.4 | 11.6 | 31 | 222 | 38 | 274 | 13 | 160 | |
| 5/ 6/81 | 100 | 467.6 | 6.3 | 11.6 | 31 | 222 | 38 | 272 | 13 | 159 | |
| 5/ 6/81 | 115 | 467.6 | 6.3 | 11.6 | 32 | 221 | 39 | 270 | 13 | 159 | |
| 5/ 6/81 | 130 | 467.6 | 6.3 | 11.6 | 31 | 222 | 38 | 272 | 13 | 159 | |
| 5/ 6/81 | 145 | 469.7 | 6.3 | 11.6 | 31 | 222 | 38 | 272 | 13 | 159 | |
| 5/ 6/81 | 200 | 469.7 | 6.4 | 11.5 | 31 | 225 | 38 | 277 | 13 | 163 | |
| 5/ 6/81 | 215 | 469.7 | 6.3 | 11.6 | 32 | 239 | 39 | 293 | 13 | 172 | |
| 5/ 6/81 | 230 | 469.7 | 6.2 | 11.6 | 32 | 243 | 38 | 295 | 13 | 173 | |
| 5/ 6/81 | 245 | 470.0 | 6.3 | 11.6 | 33 | 244 | 40 | 299 | 14 | 175 | |
| 5/ 6/81 | 300 | 470.0 | 6.3 | 11.6 | 33 | 245 | 40 | 300 | 14 | 176 | |
| 5/ 6/81 | 315 | 470.0 | 6.4 | 11.5 | 32 | 236 | 39 | 291 | 14 | 171 | |
| 5/ 6/81 | 330 | 470.0 | 6.3 | 11.6 | 32 | 161 | 39 | 197 | 13 | 115 | |
| 5/ 6/81 | 345 | 472.9 | 6.2 | 11.6 | 32 | 162 | 38 | 197 | 13 | 115 | |
| 5/ 6/81 | 400 | 472.9 | 6.3 | 11.6 | 31 | 166 | 38 | 203 | 13 | 119 | |
| 5/ 6/81 | 415 | 472.9 | 6.4 | 11.5 | 30 | 170 | 37 | 209 | 13 | 123 | |
| 5/ 6/81 | 430 | 472.9 | 6.3 | 11.5 | 30 | 169 | 36 | 207 | 13 | 121 | |
| 5/ 6/81 | 445 | 470.9 | 6.3 | 11.5 | 30 | 169 | 36 | 207 | 13 | 121 | |
| 5/ 6/81 | 500 | 470.9 | 6.3 | 11.6 | 30 | 169 | 36 | 207 | 13 | 121 | |
| 5/ 6/81 | 515 | 470.9 | 6.4 | 11.5 | 30 | 171 | 37 | 211 | 13 | 123 | |
| 5/ 6/81 | 530 | 470.9 | 6.3 | 11.5 | 30 | 171 | 36 | 209 | 13 | 123 | |
| 5/ 6/81 | 545 | 527.4 | 5.5 | 12.1 | 31 | 173 | 36 | 201 | 12 | 118 | |
| 5/ 6/81 | 600 | 527.4 | 4.7 | 12.7 | 32 | 195 | 35 | 215 | 12 | 126 | |
| 5/ 6/81 | 615 | 527.4 | 3.9 | 13.2 | 53 | 225 | 55 | 236 | 19 | 139 | |
| 5/ 6/81 | 630 | 527.4 | 4.1 | 13.0 | 43 | 254 | 45 | 270 | 16 | 158 | |
| 5/ 6/81 | 645 | 805.2 | 4.3 | 12.9 | 38 | 279 | 40 | 300 | 14 | 176 | |
| 5/ 6/81 | 700 | 805.2 | 4.3 | 12.9 | 37 | 283 | 39 | 305 | 14 | 179 | |
| 5/ 6/81 | 715 | 805.2 | 4.3 | 12.9 | 36 | 279 | 38 | 300 | 13 | 176 | |
| 5/ 6/81 | 730 | 805.2 | 4.2 | 13.0 | 35 | 278 | 37 | 299 | 13 | 175 | |
| 5/ 6/81 | 745 | 838.3 | 4.3 | 12.9 | 36 | 279 | 38 | 300 | 13 | 176 | |
| 5/ 6/81 | 800 | 838.3 | 4.1 | 13.0 | 38 | 275 | 40 | 293 | 14 | 172 | |
| 5/ 6/81 | 815 | 838.3 | 4.2 | 13.0 | 47 | 276 | 50 | 295 | 17 | 173 | |
| 5/ 6/81 | 830 | 838.3 | 4.2 | 13.0 | 42 | 282 | 45 | 302 | 16 | 177 | |
| 5/ 6/81 | 845 | 833.0 | 4.2 | 13.0 | 55 | 285 | 58 | 305 | 20 | 179 | |
| 5/ 6/81 | 900 | 833.0 | 4.3 | 12.9 | 42 | 283 | 45 | 305 | 16 | 179 | |
| 5/ 6/81 | 915 | 833.0 | 4.2 | 13.0 | 45 | 278 | 48 | 297 | 17 | 174 | |
| 5/ 6/81 | 930 | 833.0 | 4.2 | 13.0 | 40 | 276 | 42 | 295 | [illegible] | 173 | |
| 5/ 6/81 | 945 | 833.9 | 4.2 | 13.0 | 41 | 279 | 43 | 299 | [illegible] | 175 | |
| 5/ 6/81 | 1000 | 833.9 | 4.2 | 13.0 | 39 | 281 | 41 | 301 | 14 | 176 | |
| 5/ 6/81 | 1015 | 833.9 | 4.2 | 13.0 | 38 | 283 | 40 | 303 | 14 | 178 | |
| 5/ 6/81 | 1030 | 833.9 | 4.2 | 13.0 | 45 | 281 | 48 | 301 | 17 | 176 | |
| 5/ 6/81 | 1045 | 826.8 | 4.2 | 13.0 | 38 | 276 | 40 | 295 | 14 | 173 | |
| 5/ 6/81 | 1100 | 826.8 | 4.1 | 13.0 | 71 | 293 | 75 | 312 | 26 | 183 | |
| 5/ 6/81 | 1115 | 826.8 | 4.4 | 12.9 | 35 | 292 | 37 | 316 | 13 | 185 | |
| 5/ 6/81 | 1130 | 826.8 | 4.2 | 13.0 | 34 | 285 | 36 | 305 | 12 | 179 | |
| 5/ 6/81 | 1145 | 727.8 | 4.1 | 13.0 | 34 | 284 | 36 | 302 | 12 | 177 | |
| 5/ 6/81 | 1200 | 727.8 | 4.2 | 13.0 | 34 | 300 | 36 | 321 | 12 | 188 | |

*As $NO_2$

```
****************************************************************************************************
**                                  CONESVILLE UNIT 5  TEST 2
**     6                                 15 MIN. DATA
**                                DRY STACK GAS CONCENTRATION
**                             O2      CO2      CO      NO       CO      NO      CO      NO*  ACODE
**                    LOAD    VOL%     VOL%    PPMV    PPMV     PPMV    PPMV    NG/J    NG/J         **
**   DATE    TIME     MWTH    MEAS     MEAS    MEAS    MEAS     3%O2    3%O2                         **
****************************************************************************************************
** 5/ 6/81   1215    727.8    4.2     13.0      34     306       36     327      12     192          **
** 5/ 6/81   1230    727.8                                                                   C     **
** 5/ 6/81   1245    727.5                                                                   C     **
** 5/ 6/81   1300    727.5                                                                   C     **
** 5/ 6/81   1315    727.5    3.9     13.2      27     273       28     287      10     168          **
** 5/ 6/81   1330    727.5    3.9     13.1      27     272       28     286      10     168          **
** 5/ 6/81   1345    728.7    4.0     12.3      25     255       26     270       9     158          **
** 5/ 6/81   1400    728.7    3.8     13.2      27     266       28     278      10     163          **
** 5/ 6/81   1415    728.7    4.0     13.1      26     272       27     288       9     169          **
** 5/ 6/81   1430    728.7    4.0     13.1      26     277       27     293       9     172          **
** 5/ 6/81   1445    719.3    4.1     13.0      27     280       28     298      10     175          **
** 5/ 6/81   1500    719.3    3.9     13.2      26     279       27     295       9     172          **
** 5/ 6/81   1515    719.3    4.0     13.1      25     279       26     295       9     173          **
** 5/ 6/81   1530    719.3    4.0     13.1      26     279       27     295       9     173          **
** 5/ 6/81   1545    697.9    4.0     13.1      26     257       27     272       9     159          **
** 5/ 6/81   1600    697.9    4.2     13.0      26     255       27     273       9     160          **
** 5/ 6/81   1615    697.9    4.0     12.8      25     255       27     276       9     162          **
** 5/ 6/81   1630    697.9    4.4     12.8      25     242       27     262       9     154          **
** 5/ 6/81   1645    627.6    4.4     12.8      25     238       27     258       9     151          **
** 5/ 6/81   1700    627.6    4.3     12.9      25     238       26     256       9     150          **
** 5/ 6/81   1715    627.6    4.3     12.8      25     235       26     253       9     148          **
** 5/ 6/81   1730    627.6    4.4     12.8      25     234       27     253       9     149          **
** 5/ 6/81   1745    625.6    4.4     12.8      25     233       27     252       9     148          **
** 5/ 6/81   1800    625.6    4.0     12.8      25     232       27     251       9     147          **
** 5/ 6/81   1815    625.6    4.4     12.8      25     234       27     253       9     149          **
** 5/ 6/81   1830    625.6    4.4     12.8      25     233       27     252       9     148          **
** 5/ 6/81   1845    622.6    4.3     12.8      25     235       26     253       9     148          **
** 5/ 6/81   1900    622.6    4.3     12.8      25     236       26     254       9     149          **
** 5/ 6/81   1915    622.6    4.3     12.8      25     236       26     254       9     149          **
** 5/ 6/81   1930    622.6    4.3     12.8      25     238       26     256       9     150          **
** 5/ 6/81   1945    624.1    4.3     12.8      25     237       26     255       9     150          **
** 5/ 6/81   2000    624.1    4.3     12.8      25     238       26     256       9     150          **
** 5/ 6/81   2015    624.1    4.3     12.8      25     239       26     257       9     151          **
** 5/ 6/81   2030    624.1    4.3     12.8      25     238       26     256       9     150          **
** 5/ 6/81   2045    625.0    4.3     12.8      25     240       26     258       9     151          **
** 5/ 6/81   2100    625.0    4.3     12.8      25     240       26     258       9     151          **
** 5/ 6/81   2115    625.0    4.3     12.8      25     240       26     258       9     151          **
** 5/ 6/81   2130    625.0    4.3     12.8      25     241       26     259       9     152          **
** 5/ 6/81   2145    622.0    4.3     12.8      25     243       26     262       9     153          **
** 5/ 6/81   2200    622.0    4.5     12.6      24     231       26     252       9     148          **
** 5/ 6/81   2215    622.0    5.3     12.0      24     203       27     232       9     136          **
** 5/ 6/81   2230    622.0    5.8     11.6      24     248       28     295      10     173          **
** 5/ 6/81   2245    480.8    5.8     11.6      24     231       28     273      10     160          **
** 5/ 6/81   2300    480.8    5.8     11.6      24     234       28     277      10     162          **
** 5/ 6/81   2315    480.8    5.8     11.6      23     241       27     285       9     167          **
** 5/ 6/81   2330    480.8    5.8     11.6      24     249       28     295      10     173          **
** 5/ 6/81   2345    466.7    5.7     11.6      24     273       28     321      10     188          **
** 5/ 6/81   2400    466.7    5.8     11.6      24     274       28     324      10     190          **
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*As $NO_2$

7

## CONESVILLE UNIT 5 TEST 2
## 15 MIN. DATA
## DRY STACK GAS CONCENTRATION

| DATE | TIME | LOAD MWTH | O2 VOL% MEAS | CO2 VOL% MEAS | CO PPMV MEAS | NO PPMV MEAS | CO PPMV 3%O2 | NO PPMV 3%O2 | CO NG/J | NO* NG/J | ACODE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5/ 7/81 | 15 | 465.0 | 5.8 | 11.6 | 24 | 276 | 28 | 327 | 10 | 192 | |
| 5/ 7/81 | 30 | 465.0 | 5.8 | 11.6 | 24 | 275 | 28 | 325 | 10 | 191 | |
| 5/ 7/81 | 45 | 465.0 | 5.8 | 11.6 | 25 | 271 | 29 | 321 | 10 | 188 | |
| 5/ 7/81 | 100 | 465.0 | 5.7 | 11.6 | 25 | 270 | 29 | 317 | 10 | 186 | |
| 5/ 7/81 | 115 | 465.0 | 5.7 | 11.7 | 25 | 270 | 29 | 317 | 10 | 186 | |
| 5/ 7/81 | 130 | 465.0 | 5.7 | 11.6 | 24 | 272 | 28 | 320 | 10 | 188 | |
| 5/ 7/81 | 145 | 462.9 | 5.7 | 11.6 | 24 | 270 | 28 | 317 | 10 | 186 | |
| 5/ 7/81 | 200 | 462.9 | 5.7 | 11.6 | 24 | 273 | 28 | 321 | 10 | 188 | |
| 5/ 7/81 | 215 | 462.9 | 5.7 | 11.6 | 24 | 275 | 28 | 323 | 10 | 190 | |
| 5/ 7/81 | 230 | 462.9 | 5.6 | 11.6 | 25 | 273 | 29 | 319 | 10 | 187 | |
| 5/ 7/81 | 245 | 462.6 | 5.7 | 11.6 | 25 | 273 | 29 | 321 | 10 | 188 | |
| 5/ 7/81 | 300 | 462.6 | 5.7 | 11.6 | 25 | 271 | 29 | 319 | 10 | 187 | |
| 5/ 7/81 | 315 | 462.6 | 5.7 | 11.6 | 25 | 270 | 29 | 317 | 10 | 186 | |
| 5/ 7/81 | 330 | 462.6 | 5.7 | 11.6 | 25 | 274 | 29 | 322 | 10 | 189 | |
| 5/ 7/81 | 345 | 462.9 | 5.6 | 11.6 | 25 | 275 | 29 | 321 | 10 | 188 | |
| 5/ 7/81 | 400 | 462.9 | 5.5 | 11.7 | 25 | 276 | 29 | 320 | 10 | 188 | |
| 5/ 7/81 | 415 | 462.9 | 5.6 | 11.6 | 25 | 278 | 29 | 325 | 10 | 190 | |
| 5/ 7/81 | 430 | 462.7 | 5.7 | 11.5 | 25 | 282 | 29 | 332 | 10 | 194 | |
| 5/ 7/81 | 445 | 462.6 | 5.5 | 11.6 | 25 | 276 | 29 | 320 | 10 | 188 | |
| 5/ 7/81 | 500 | 462.6 | 5.6 | 11.6 | 25 | 277 | 29 | 324 | 10 | 190 | |
| 5/ 7/81 | 515 | 462.6 | 5.6 | 11.6 | 25 | 276 | 29 | 322 | 10 | 189 | |
| 5/ 7/81 | 530 | 462.6 | 5.5 | 11.7 | 25 | 273 | 29 | 317 | 10 | 186 | |
| 5/ 7/81 | 545 | 512.7 | 5.1 | 12.0 | 25 | 241 | 28 | 273 | 10 | 160 | |
| 5/ 7/81 | 600 | 512.7 | 4.3 | 12.7 | 26 | 241 | 28 | 259 | 9 | 152 | |
| 5/ 7/81 | 615 | 512.7 | 3.8 | 13.1 | 26 | 261 | 27 | 273 | 9 | 160 | |
| 5/ 7/81 | 630 | 512.7 | 3.5 | 13.3 | 27 | 281 | 27 | 289 | 9 | 169 | |
| 5/ 7/81 | 645 | 786.7 | 3.7 | 13.1 | 33 | 280 | 34 | 291 | 12 | 171 | |
| 5/ 7/81 | 700 | 786.7 | 3.8 | 13.0 | 33 | 278 | 34 | 291 | 12 | 170 | |
| 5/ 7/81 | 715 | 786.7 | 3.7 | 13.1 | 31 | 284 | 32 | 295 | 11 | 173 | |
| 5/ 7/81 | 730 | 786.7 | 3.7 | 13.1 | 34 | 287 | 35 | 298 | 12 | 175 | |
| 5/ 7/81 | 745 | 832.7 | 3.7 | 13.1 | 29 | 287 | 30 | 298 | 10 | 175 | |
| 5/ 7/81 | 800 | 832.7 | 3.7 | 13.1 | 28 | 286 | 29 | 297 | 10 | 174 | |
| 5/ 7/81 | 815 | 832.7 | | | | | | | | | C |
| 5/ 7/81 | 830 | 832.7 | | | | | | | | | C |
| 5/ 7/81 | 845 | 834.5 | 4.2 | 13.0 | 31 | 279 | 33 | 299 | 11 | 175 | |
| 5/ 7/81 | 900 | 834.5 | 4.2 | 13.0 | 31 | 277 | 33 | 296 | 11 | 174 | |
| 5/ 7/81 | 915 | 834.5 | 4.2 | 13.0 | 18 | 279 | 19 | 299 | 6 | 175 | |
| 5/ 7/81 | 930 | 834.5 | 4.2 | 13.0 | 32 | 277 | 34 | 296 | 12 | 174 | |
| 5/ 7/81 | 945 | 840.9 | 4.2 | 13.0 | 32 | 278 | 34 | 297 | 12 | 174 | |
| 5/ 7/81 | 1000 | 840.9 | 4.2 | 13.0 | 38 | 278 | 40 | 297 | 14 | 174 | |
| 5/ 7/81 | 1015 | 840.9 | | | | | | | | | I |
| 5/ 7/81 | 1030 | 840.9 | 4.3 | 13.0 | 30 | 283 | 32 | 303 | 11 | 178 | |
| 5/ 7/81 | 1045 | 822.5 | 4.3 | 12.9 | 47 | 273 | 50 | 298 | 18 | 172 | |
| 5/ 7/81 | 1100 | 822.5 | 3.7 | 13.3 | 42 | 283 | 43 | 298 | 15 | 172 | |
| 5/ 7/81 | 1115 | 822.5 | 3.9 | 13.2 | 39 | 301 | 41 | 316 | 14 | 186 | |
| 5/ 7/81 | 1130 | 822.5 | 3.9 | 13.2 | 39 | 300 | 41 | 315 | 14 | 185 | |
| 5/ 7/81 | 1145 | 835.9 | 3.9 | 13.2 | 49 | 298 | 51 | 313 | 18 | 184 | |
| 5/ 7/81 | 1200 | 835.9 | 4.0 | 13.2 | 35 | 298 | 37 | 315 | 13 | 185 | |

*As $NO_2$

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*************************************************************************************************
**                                  CONESVILLE UNIT 5  TEST 2                                  **
**                                        15 MIN. DATA                                         **
**                                 DRY STACK GAS CONCENTRATION                             *   **
**                          O2     CO2     CO      NO      CO      NO      CO      NO   ACODE  **
**                  LOAD   VOL%    VOL%   PPMV    PPMV    PPMV    PPMV   NG/J    NG/J          **
**  DATE    TIME    MWTH   MEAS    MEAS   MEAS    MEAS    3%O2    3%O2                         **
*************************************************************************************************
** 5/ 7/81  1830   654.9    6.6    11.7     25     230      31     287     11     169          **
** 5/ 7/81  1845   482.3    6.5    11.7     27     224      33     278     11     163          **
** 5/ 7/81  1900   482.3    6.5    11.7     27     223      33     277     11     162          **
** 5/ 7/81  1915   482.3    6.5    11.8     30     161      37     200     13     117          **
** 5/ 7/81  1930   482.3    5.2    12.7     27     149      30     169     10      99          **
** 5/ 7/81  1945   611.5    4.8    12.9     27     204      30     226     10     133          **
** 5/ 7/81  2000   611.5    4.2    13.3     50     229      53     245     19     144          **
** 5/ 7/81  2015   611.5    4.2    13.3    156     237     167     254     59     149          **
** 5/ 7/81  2030   611.5    4.1    13.3    226     224     240     238     85     140          **
** 5/ 7/81  2045   813.7    4.1    13.3    108     261     115     278     40     163          **
** 5/ 7/81  2100   813.7    4.1    13.3     62     262      66     279     23     163          **
** 5/ 7/81  2115   813.7    4.1    13.3     65     272      69     289     24     170          **
** 5/ 7/81  2130   813.7    4.2    13.3     72     262      77     280     27     164          **
** 5/ 7/81  2145   840.9    4.1    13.3     81     261      86     278     30     163          **
** 5/ 7/81  2200   840.9    4.6    13.0     40     270      43     296     15     174          **
** 5/ 7/81  2215   840.9    5.3    12.5     30     254      34     291     12     171          **
** 5/ 7/81  2230   840.9    6.0    12.0     27     219      32     263     11     154          **
** 5/ 7/81  2245   670.7    6.1    12.0     26     223      31     269     11     158          **
** 5/ 7/81  2300   670.7    6.7    11.5     26     242      32     305     11     179          **
** 5/ 7/81  2315   670.7    7.0    11.2     25     262      32     337     11     198          **
** 5/ 7/81  2330   670.7    7.0    11.2     25     270      32     347     11     204          **
** 5/ 7/81  2345   470.9    7.0    11.2     25     268      32     345     11     202          **
** 5/ 7/81  2400   470.9    7.0    11.2     25     268      32     345     11     202          **
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*As $NO_2$

9

CONESVILLE UNIT 5 TEST 2
15 MIN. DATA
DRY STACK GAS CONCENTRATION

| DATE | TIME | LOAD MWTH | O2 VOL% MEAS | CO2 VOL% MEAS | CO PPMV MEAS | NO PPMV MEAS | CO PPMV 3%O2 | NO PPMV 3%O2 | CO NG/J | NO* NG/J | ACODE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5/ 8/81 | 15 | 468.8 | 7.0 | 11.2 | 26 | 267 | 33 | 343 | 11 | 201 | |
| 5/ 8/81 | 30 | 468.8 | 6.9 | 11.2 | 26 | 267 | 33 | 341 | 11 | 200 | |
| 5/ 8/81 | 45 | 468.8 | 6.9 | 11.2 | 26 | 267 | 33 | 341 | 11 | 200 | |
| 5/ 8/81 | 100 | 468.8 | 6.9 | 11.2 | 26 | 263 | 33 | 336 | 11 | 197 | |
| 5/ 8/81 | 115 | 468.8 | 6.9 | 11.2 | 26 | 266 | 33 | 340 | 11 | 199 | |
| 5/ 8/81 | 130 | 468.8 | 6.8 | 11.3 | 26 | 266 | 33 | 337 | 11 | 198 | |
| 5/ 8/81 | 145 | 468.5 | 6.8 | 11.2 | 26 | 267 | 33 | 338 | 11 | 199 | |
| 5/ 8/81 | 200 | 468.5 | 6.9 | 11.2 | 26 | 267 | 33 | 341 | 11 | 200 | |
| 5/ 8/81 | 215 | 468.5 | 6.8 | 11.2 | 26 | 267 | 33 | 338 | 11 | 199 | |
| 5/ 8/81 | 230 | 468.5 | 6.8 | 11.2 | 26 | 265 | 33 | 336 | 11 | 197 | |
| 5/ 8/81 | 245 | 468.2 | 6.8 | 11.2 | 26 | 262 | 33 | 332 | 11 | 195 | |
| 5/ 8/81 | 300 | 468.2 | 6.8 | 11.2 | 26 | 263 | 33 | 333 | 11 | 196 | |
| 5/ 8/81 | 315 | 468.2 | 6.7 | 11.2 | 26 | 262 | 32 | 330 | 11 | 193 | |
| 5/ 8/81 | 330 | 468.2 | 6.8 | 11.1 | 25 | 268 | 31 | 340 | 11 | 199 | |
| 5/ 8/81 | 345 | 468.2 | 6.7 | 11.3 | 26 | 266 | 32 | 335 | 11 | 196 | |
| 5/ 8/81 | 400 | 468.2 | 6.7 | 11.2 | 26 | 274 | 32 | 345 | 11 | 202 | |
| 5/ 8/81 | 415 | 468.2 | 6.7 | 11.2 | 26 | 281 | 32 | 354 | 11 | 207 | |
| 5/ 8/81 | 430 | 468.2 | 6.7 | 11.2 | 26 | 276 | 32 | 347 | 11 | 204 | |
| 5/ 8/81 | 445 | 484.6 | 6.7 | 11.2 | 26 | 277 | 32 | 349 | 11 | 205 | |
| 5/ 8/81 | 500 | 484.6 | 6.4 | 11.5 | 26 | 240 | 32 | 296 | 11 | 173 | |
| 5/ 8/81 | 515 | 484.6 | 5.9 | 11.8 | 26 | 237 | 31 | 282 | 11 | 166 | |
| 5/ 8/81 | 530 | 484.6 | 5.5 | 12.1 | 27 | 224 | 31 | 260 | 11 | 152 | |
| 5/ 8/81 | 545 | 747.4 | 5.4 | 12.2 | 28 | 231 | 32 | 266 | 11 | 156 | |
| 5/ 8/81 | 600 | 747.4 | 5.4 | 12.2 | 26 | 278 | 30 | 321 | 10 | 188 | |
| 5/ 8/81 | 615 | 747.4 | 5.3 | 12.3 | 26 | 282 | 29 | 323 | 10 | 189 | |
| 5/ 8/81 | 630 | 747.4 | 5.3 | 12.3 | 26 | 286 | 29 | 328 | 10 | 192 | |
| 5/ 8/81 | 645 | 842.4 | 5.3 | 12.3 | 26 | 289 | 29 | 331 | 10 | 194 | |
| 5/ 8/81 | 700 | 842.4 | 5.3 | 12.2 | 26 | 290 | 29 | 332 | 10 | 195 | |
| 5/ 8/81 | 715 | 842.4 | 5.4 | 12.2 | 26 | 291 | 30 | 336 | 10 | 197 | |
| 5/ 8/81 | 730 | 842.4 | 5.4 | 12.1 | 26 | 294 | 30 | 339 | 10 | 199 | |
| 5/ 8/81 | 745 | 845.3 | 5.4 | 12.1 | 26 | 295 | 30 | 340 | 10 | 200 | |
| 5/ 8/81 | 800 | 845.3 | 5.5 | 12.1 | 25 | 297 | 29 | 345 | 10 | 202 | |
| 5/ 8/81 | 815 | 845.3 | | | | | | | | | C |
| 5/ 8/81 | 830 | 845.3 | | | | | | | | | C |
| 5/ 8/81 | 845 | 850.6 | 5.2 | 12.4 | 29 | 288 | 33 | 323 | 11 | 190 | |
| 5/ 8/81 | 900 | 850.6 | 5.5 | 12.3 | 30 | 285 | 34 | 331 | 12 | 194 | |
| 5/ 8/81 | 915 | 850.6 | 5.5 | 12.2 | 31 | 283 | 36 | 328 | 12 | 193 | |
| 5/ 8/81 | 930 | 850.6 | 5.4 | 12.3 | 32 | 283 | 36 | 326 | 13 | 191 | |
| 5/ 8/81 | 945 | 848.2 | 5.3 | 12.4 | 33 | 279 | 37 | 320 | 13 | 187 | |
| 5/ 8/81 | 1000 | 848.2 | 5.2 | 12.4 | 33 | 277 | 37 | 315 | 13 | 185 | |

*As $NO_2$

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*******************************************************************************************
**                               CONESVILLE UNIT 5  TEST 2                               **
**   /1                                  15 MIN. DATA                                    **
**                             DRY STACK GAS CONCENTRATION                  *            **
**                             O2      CO2     CO      NO      CO      NO      CO      NO   ACODE  **
**                   LOAD     VOL%    VOL%    PPMV    PPMV    PPMV    PPMV    NG/J    NG/J         **
**   DATE     TIME   MWTH     MEAS    MEAS    MEAS    MEAS    3%O2    3%O2                          **
*******************************************************************************************
** 5/ 9/81    930    846.8    6.1     11.7    28      314     33      379     12      222          **
** 5/ 9/81    945    844.1    5.8     11.9    30      305     35      361     12      212          **
** 5/ 9/81   1000    844.1    5.8     11.8    31      305     36      361     13      212          **
** 5/ 9/81   1015    844.1                                                                  I    **
** 5/ 9/81   1030    844.1    5.6     11.7    30      185     35      216     12      127          **
** 5/ 9/81   1045    842.1    5.5     11.9    31      187     36      217     12      127          **
** 5/ 9/81   1100    842.1    5.5     11.9    31      266     36      309     12      181          **
** 5/ 9/81   1115    842.1    5.3     12.1    30       53     34       60     12       35          **
** 5/ 9/81   1130    842.1    5.6     12.0    28       -1     32       -1     11       -1          **
** 5/ 9/81   1145    771.2    5.6     12.0    28      168     32      194     11      113          **
** 5/ 9/81   1200    771.2    5.6     11.9    27       -1     31       -1     11       -1          **
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*As $NO_2$

CONESVILLE UNIT 5 TEST 2
15 MIN. DATA
DRY STACK GAS CONCENTRATION

| DATE | TIME | LOAD MWTH | O2 VOL% MEAS | CO2 VOL% MEAS | CO PPMV MEAS | NO PPMV MEAS | CO PPMV 3%O2 | NO PPMV 3%O2 | CO NG/J | NO* NG/J | ACODE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5/ 9/81 | 1215 | 771.2 | .0 | .0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 5/ 9/81 | 1230 | 771.2 | 5.5 | 12.1 | 27 | 222 | 31 | 258 | 11 | 151 | |
| ~~5/ 9/81~~ | ~~1245~~ | ~~633.8~~ | ~~6.1~~ | ~~11.5~~ | ~~27~~ | ~~249~~ | ~~32~~ | ~~301~~ | ~~11~~ | ~~176~~ | |
| 5/ 9/81 | 1300 | 633.8 | 6.4 | 11.3 | 27 | 261 | 33 | 322 | 11 | 189 | |
| 5/ 9/81 | 1315 | 633.8 | 6.7 | 10.9 | 27 | 288 | 34 | 363 | 12 | 213 | |
| ~~5/ 9/81~~ | ~~1330~~ | ~~633.8~~ | ~~7.2~~ | ~~10.5~~ | ~~27~~ | ~~300~~ | ~~35~~ | ~~391~~ | ~~12~~ | ~~230~~ | |
| 5/ 9/81 | 1345 | 477.9 | 7.1 | 10.5 | 27 | 296 | 35 | 383 | 12 | 225 | |
| 5/ 9/81 | 1400 | 477.9 | 7.0 | 10.6 | 28 | 282 | 36 | 363 | 12 | 213 | |
| ~~5/ 9/81~~ | ~~1415~~ | ~~477.9~~ | | | | | | | | | ~~I~~ |
| 5/ 9/81 | 1430 | 477.9 | | | | | | | | | C |
| 5/ 9/81 | 1445 | 514.5 | 6.9 | 10.7 | 28 | 275 | 35 | 351 | 12 | 206 | |
| ~~5/ 9/81~~ | ~~1500~~ | ~~514.5~~ | ~~6.8~~ | ~~10.8~~ | ~~27~~ | ~~275~~ | ~~34~~ | ~~349~~ | ~~12~~ | ~~204~~ | |
| 5/ 9/81 | 1515 | 514.5 | 6.8 | 10.8 | 28 | 275 | 35 | 349 | 12 | 204 | |
| 5/ 9/81 | 1530 | 514.5 | 6.8 | 10.7 | 28 | 274 | 35 | 347 | 12 | 204 | |
| ~~5/ 9/81~~ | ~~1545~~ | ~~533.8~~ | ~~6.6~~ | ~~10.9~~ | ~~28~~ | ~~259~~ | ~~35~~ | ~~324~~ | ~~12~~ | ~~190~~ | |
| 5/ 9/81 | 1600 | 533.8 | 5.7 | 11.7 | 29 | 229 | 34 | 269 | 12 | 158 | |
| 5/ 9/81 | 1615 | 533.8 | 5.1 | 12.1 | 29 | 234 | 32 | 265 | 11 | 155 | |
| ~~5/ 9/81~~ | ~~1630~~ | ~~533.8~~ | ~~5.3~~ | ~~11.9~~ | ~~29~~ | ~~272~~ | ~~33~~ | ~~312~~ | ~~11~~ | ~~183~~ | |
| 5/ 9/81 | 1645 | 827.1 | 5.4 | 11.9 | 29 | 289 | 33 | 333 | 11 | 195 | |
| 5/ 9/81 | 1700 | 827.1 | 5.3 | 11.9 | 28 | 290 | 32 | 332 | 11 | 195 | |
| ~~5/ 9/81~~ | ~~1715~~ | ~~827.1~~ | ~~5.3~~ | ~~12.0~~ | ~~28~~ | ~~293~~ | ~~32~~ | ~~336~~ | ~~11~~ | ~~197~~ | |
| 5/ 9/81 | 1730 | 827.1 | 5.4 | 11.9 | 28 | 299 | 32 | 345 | 11 | 202 | |
| 5/ 9/81 | 1745 | 702.9 | 5.4 | 11.9 | 28 | 294 | 32 | 339 | 11 | 199 | |
| ~~5/ 9/81~~ | ~~1800~~ | ~~702.9~~ | ~~5.2~~ | ~~12.0~~ | ~~29~~ | ~~291~~ | ~~33~~ | ~~331~~ | ~~11~~ | ~~194~~ | |
| 5/ 9/81 | 1815 | 702.9 | 5.3 | 11.9 | 29 | 291 | 33 | 333 | 11 | 196 | |
| 5/ 9/81 | 1830 | 702.9 | 5.2 | 12.0 | 29 | 278 | 33 | 316 | 11 | 186 | |
| ~~5/ 9/81~~ | ~~1845~~ | ~~687.1~~ | ~~5.1~~ | ~~12.0~~ | ~~29~~ | ~~279~~ | ~~32~~ | ~~316~~ | ~~11~~ | ~~185~~ | |
| 5/ 9/81 | 1900 | 687.1 | 5.1 | 12.0 | 29 | 280 | 32 | 317 | 11 | 186 | |
| 5/ 9/81 | 1915 | 687.1 | 5.0 | 12.1 | 29 | 279 | 32 | 314 | 11 | 184 | |
| ~~5/ 9/81~~ | ~~1930~~ | ~~687.1~~ | ~~5.1~~ | ~~12.1~~ | ~~28~~ | | ~~31~~ | | ~~11~~ | | ~~D~~ |
| 5/ 9/81 | 1945 | 693.5 | 5.1 | 12.0 | 29 | | 32 | | 11 | | D |
| 5/ 9/81 | 2000 | 693.5 | 5.0 | 12.1 | 29 | | 32 | | 11 | | D |
| ~~5/ 9/81~~ | ~~2015~~ | ~~693.5~~ | ~~5.1~~ | ~~12.0~~ | ~~29~~ | | ~~32~~ | | ~~11~~ | | ~~D~~ |
| 5/ 9/81 | 2030 | 693.5 | 5.1 | 12.0 | 29 | | 32 | | 11 | | D |
| 5/ 9/81 | 2045 | 813.7 | 4.9 | 12.1 | 29 | | 32 | | 11 | | D |
| ~~5/ 9/81~~ | ~~2100~~ | ~~813.7~~ | ~~5.3~~ | ~~11.8~~ | ~~29~~ | | ~~33~~ | | ~~11~~ | | ~~D~~ |
| 5/ 9/81 | 2115 | 813.7 | 5.0 | 12.1 | 30 | | 33 | | 12 | | D |
| 5/ 9/81 | 2130 | 813.7 | 6.1 | 11.0 | 28 | | 33 | | 12 | | D |
| ~~5/ 9/81~~ | ~~2145~~ | ~~544.4~~ | ~~6.3~~ | ~~10.9~~ | ~~28~~ | | ~~34~~ | | ~~12~~ | | ~~D~~ |
| 5/ 9/81 | 2200 | 544.4 | 6.6 | 10.5 | 28 | | 35 | | 12 | | D |
| 5/ 9/81 | 2215 | 544.4 | 6.6 | 10.5 | 28 | | 35 | | 12 | | D |
| ~~5/ 9/81~~ | ~~2230~~ | ~~544.4~~ | ~~6.7~~ | ~~10.4~~ | ~~28~~ | | ~~35~~ | | ~~12~~ | | ~~D~~ |
| 5/ 9/81 | 2245 | 473.8 | 6.5 | 10.6 | 29 | | 36 | | 12 | | D |
| 5/ 9/81 | 2300 | 473.8 | 6.5 | 10.6 | 29 | | 36 | | 12 | | D |
| ~~5/ 9/81~~ | ~~2315~~ | ~~473.8~~ | ~~6.5~~ | ~~10.5~~ | ~~29~~ | | ~~36~~ | | ~~12~~ | | ~~D~~ |
| 5/ 9/81 | 2330 | 473.8 | 6.5 | 10.5 | 29 | | 36 | | 12 | | D |
| 5/ 9/81 | 2345 | 474.4 | 6.4 | 10.6 | 29 | | 35 | | 12 | | D |
| ~~5/ 9/81~~ | ~~2400~~ | ~~474.4~~ | ~~6.5~~ | ~~10.5~~ | ~~29~~ | | ~~36~~ | | ~~12~~ | | ~~D~~ |

*As $NO_2$